GENERALIZED HELICOPTER ROTOR PERFORMANCE PREDICTIONS

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NAVAL POSTGRADUATE SCHOOL

Monterey, California

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GENERALIZED HELICOPTER ROTOR
PERFORMANCE PREDICTIONS

by

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The goals of this thesis were (1) to reinvestigate the theory and logic used in the program, (2) to add selected desirable features to the program, (3) to produce a much needed Users' Manual, and (4) to run an analysis comparing the program's calculated results against manufacturer's data. These goals were accomplished and the results of the analysis indicated that the program produces highly accurate results within the normal cruise range of a modern helicopter.

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Generalized Helicopter Rotor Performance Predictions

by

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ABSTRACT

The Generalized Rotor Performance (GRP) program is a computer program designed for calculating forward flight performance of a helicopter rotor system at a specific flight condition. It can be used to evaluate either an articulated or a hingeless single rotor system in forward flight or in a wind-tunnel test. The program was originally designed by the Sikorsky Aircraft Company and purchased by the United States Navy.

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CD	Sectional Coefficient of Drag
CL	Sectional Coefficient of Lift
CM	Sectional Coefficent of Moment
U	Resultant of UP, UT and UR velocities
UP	Velocity perpendicular to the plane of rotation
UR	Velocity in radial direction in plane of rotation
UT	Velocity tangential to the plane of rotation
UTUR	Resultant of UT and UR velocities
C.75	Chord at 75 percent blade radius
V	Forward flight velocity, feet per seconds
a	Lift Curve Slope, rad^{-1}
α_s	Shaft axis angle, degrees
β	Blade flapping angle
λ	LAMBDA, Inflow Ratio in shaft axis system
Ω	Blade rotational velocity, radians per second
$\theta_{.75}$	Pitch Angle at the 75 percent radius point at the PSI equal zero azimuthal position
ψ	PSI, blade azimuthal position
μ	Advance Ratio in the shaft axis reference system $\mu = V \cos \alpha_s / \Omega R$
ρ	Air Density

I. INTRODUCTION

The Generalized Rotor Performance (GRP) program is a computer program designed for calculating forward flight performance of a helicopter rotor system at a specific flight condition. It can be used to evaluate either an articulated or a hingeless single rotor system in forward flight or in a wind-tunnel test. The GRP series of programs were originally designed by the Sikorsky Aircraft Corporation with the cooperation of the United Aircraft Research Laboratories. Work began on this series of programs in 1955 and has continued to date. The United States Navy purchased this program in 1964 and has used it in the Naval Air Systems Command as a helicopter performance computer program.

The goals of this thesis were (1) to reinvestigate the theory and logic used in the program, (2) to ensure that the Navy's version of this program performed the calculations according to the design theory, (3) to produce a much needed Users' Manual, (4) to add certain desirable features to and correct errors found in the program, (5) to run an analysis comparing the program's calculated results against manufacturer's data and (6) to document areas that may need further attention. The work was done with the help and cooperation of both faculty at the Naval Postgraduate School and personnel in the Naval Air System Command.

The output available from the program includes rotor shaft horsepower, rotor profile horsepower, main rotor torque, lift, drag, thrust, H force, rolling and pitching moments and other forces and moments calculated in the shaft, control and relative wind reference axis systems. Also available are the azimuthal histories of the blade's flapping angles, rates and accelerations, plus azimuthal and

radial histories of angles of attack, CL, CD, Mach number, sweep angles and air load distribution. In addition, the program will calculate a Fourier coefficient series for flapping angle, radial station air loads and azimuthal Z force distribution.

The program can be divided figuratively into three main routines. The first routine determines a steady state flapping solution. The second routine determines the forces and moments generated by this flapping solution. The third routine compares the calculated results of lift, drag and other options to those desired by the user. If the calculated values are not within a predetermined tolerance, the program will, by use of a first order Taylor series, generate new values to reenter into the blade flapping routine.

The program uses a combined blade element/momentum strip theory. The blade's radius is divided into a maximum of 15 segments. The blade is advanced around the azimuth in a prescribed number of degrees. At each particular azimuthal position, velocities are computed in the perpendicular (UP), tangential (UT) and radial (UR) directions. From these velocities and a known pitch angle distribution, the local angles of attack are calculated. From these angles of attack, the forces at each radial blade segment are determined. Once the forces are known, the local moments can be found. From the summation of these moments at a particular azimuthal position, the blade flapping acceleration is calculated. This acceleration, combined with the calculated flapping angle and rate, is used to advance the blade to the next azimuthal position. A steady state flapping condition is assumed to exist when the blade flapping angle and rate at the PSI equal zero and 360 degree azimuthal position are within a prescribed tolerance of each other.

This method of calculation accounts for retreating blade stall, the reverse flow region and compressibility effects. The program can accommodate a full range of geometric and design variables including flapping hinge offset, elastic flapping hinge restraint, first and second harmonic cyclic inputs and spanwise variations in blade twist, local mass densities, chord and tip sweep. The program uses no small angle assumptions and has no restrictions on tip speed, forward velocity or advance ratio. The rotor system can be oriented in any direction in space and can be given any rotor shaft or aircraft roll, pitch or yaw angular velocities. The program will perform calculations in straight and level flight or a uniform induced velocity may be added to simulate climbs and descents. The GRP will accept up to five different airfoil data decks plus one blade spar characteristics data deck. Lift and drag information is entered into the program in the form of CL and CD versus Angle of Attack Tables for up to 15 different Mach numbers. The user has a choice of six methods of solution depending upon the desired restrictions. The user has available nine printout options, two of which are program debugging options. There are also error printout messages that will assist the user having difficulty with the program.

In the method described above, the flapping motion determined is about a flapping hinge offset, and with the elimination of all assumptions that the flapping angles are small, the rotor control axis (axis of no feathering) and the tip path plane axis (axis of no first harmonic flapping) are no longer considered convenient for reference in the analysis of rotor blade motion. Therefore, the axis selected for use in the analysis is the rotor shaft axis system. All forces, moments and angles are referred to the shaft axis system with the exception of some of the final output forces which are referred to the relative wind and control axis systems.

With the use of the computer, the GRP program eliminated many of the simpliflying assumptions of the earlier classical theory originated by Wheatley and Bailey in Ref. 1 and 2. The assumptions of the classical theory did not impose serious limitations in low speed flight, but as helicopter speeds increase, the inaccuracies inherent in the theory seriously limit the usefulness of this method. The assumptions of the Wheatley-Bailey theory which are not present in the GRP program include the following.

1. The flapping and inflow angles are assumed small.
2. The lift and drag coefficients are approximated by a linear and a quadratic variation, respectively, with angle of attack.
3. The effects of Mach number on CL and CD are not considered.
4. Sectional characteristics in the reverse flow region are the same as those in the conventional flow.
5. The sectional characteristics of blade twist, tip sweep, flapping hinge offset and root cut out are ignored.

While the GRP program represents a refined approach to the classical theory, there are still some basic assumptions which make the GRP subject to error. These are:

1. Steady state two-dimensional airfoil data are used.
2. Quasi-static blade analysis is used.
3. The rotational speed about the shaft axis is constant. There is no lead or lag motion in the program.
4. The rotor blade is assumed rigid in bending and torsion.

5. The rotor inflow is assumed uniform unless varied by the user.
6. Spanwise flow is incorporated into the calculation of blade angle of attack; however, it is assumed that the flow at one segment does not affect the flow at any other segment.

It is felt that the errors induced by the above assumptions are relatively small in the normal cruise speed region of a modern helicopter. This is the region from just below the minimum power airspeed to the maximum allowable cruise speed. The program can not calculate rotor hover power. This is because one of the factors in the denominator in the main routine which estimates new flapping routine reentry parameters is the advance ratio. Since the advance ratio is zero in a hover, the computer would attempt to divide here by the number zero. Highly accurate results are not available in the airspeed region from hover to just below the minimum power airspeed while using the normal uniform inflow assumption. This is a region of highly non-uniform flow. Variable inflow may be inputed by the user. However, at this time, no information is available on how successful this technique is in accurately estimating the required rotor system horsepower. While the program's required technique for inducing harmonic variable flow is cumbersome, Bramwell in Chapter Four of Ref. 6 describes several methods which could be incorporated into the program.

The quasi-static blade analysis assumption is valid except in the very high speed region where a large percentage of the retreating blade is in a stalled condition. This is an area of aerodynamic hysteresis that is influenced by unsteady aerodynamics. While encountering lift hysteresis, the amount of lift change above the steady state CL is about the same as below. However, the lift distribution on the rotor disc will change. Stall is delayed and occurs at a slightly later azimuthal station

then predicted by quasi-static analysis. While difficult, complicated and computer-time-consuming procedures can be taken to reduce these assumptions there is no guarantee that the accuracy of the solution will improve. It is felt that the present program produces highly accurate results in the flight range of interest in a modern helicopter.

II. METHOD OF ANALYSIS

A. GENERAL COMMENTS

The GRP uses a combined blade element/momentum strip theory in its calcultions. The blade radius is divided into a maximum of 15 segments or strips. Figure 1 illustrates a typical blade element. In order to obtain a steady state flapping solution the program must calculate the time history of the flapping motion. This necessitates a complete knowledge of the flapping angles, rates and accelerations. The time history of this motion must be found by solving the highly non-linear equation for the summation of moments about the flapping hinge. Figure 2 illustrates the forces which produce moments on the rotor system. The blade has aerodynamic forces acting upwards, blade weight acting downwards, centrifugal force acting outwards, an optional elastic hinge restraint acting to return the blade to a zero flapping angle and an inertia force resisting any change in blade flapping. The moment summation equation about the flapping hinge may be written as

$$(1) \quad M_{AERO} + M_{W} + M_{I} + M_{CF} + M_{EHR} = 0.$$

The moment due to inertia force can be expressed as $I_b\ddot{\beta}$, where I_b is the blade moment of inertia about the flapping hinge. Substituting this into equation 1 and solving for $\ddot{\beta}$, the following governing equation is obtained.

$$(2) \quad \ddot{\beta} = \frac{M_{AERO} + M_{W} + M_{CF} + M_{EHR}}{I_b}$$

If the angle of attack and local Mach number at each blade segment were known, the CL and CD could be obtained

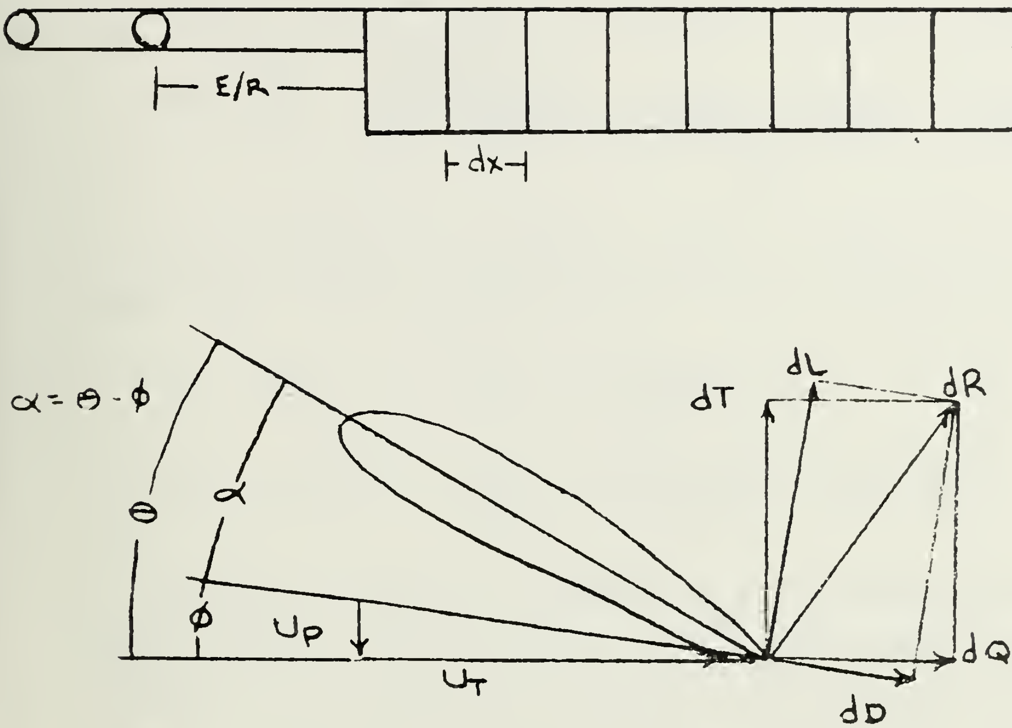


Figure 1 Blade Element Diagram

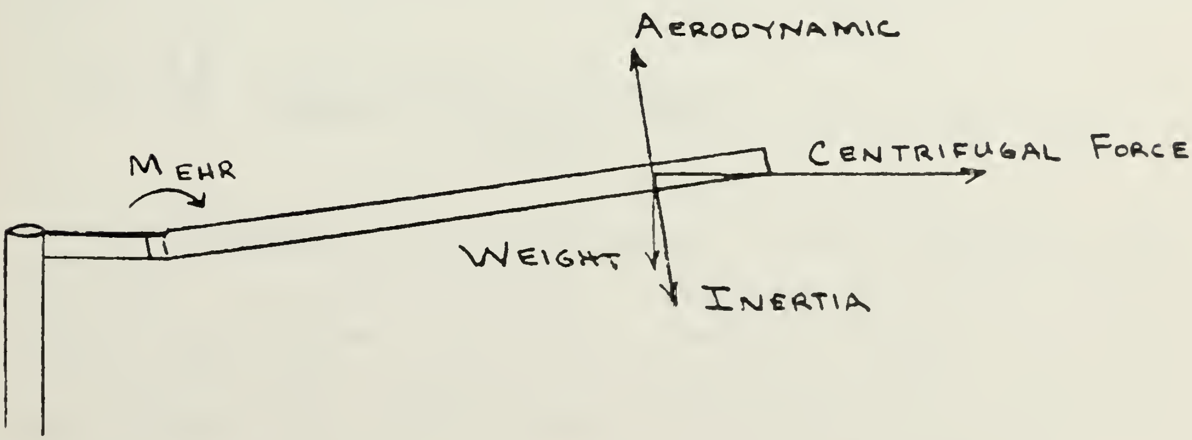


Figure 2 Rotor Blade Moment Diagram

from the inputed airfoil information. The local aerodynamic forces and moments can be calculated and the flapping acceleration determined. Equation 2 can be rewritten as

$$(3) \quad \ddot{\beta}_n = \sum_{i=1}^{K\ \text{segments}} \frac{(dM_{AERO_i} + dM_{W_i} + dM_{CF_i} + dM_{EHR_i})}{I_b}$$

The flapping angle and rate at the (N + 1) azimuthal position could be obtained from the following expressions.

$$(4) \quad \dot{\beta}_{n+1} = \dot{\beta}_n + \ddot{\beta}_n \Delta t$$

$$(5) \quad \beta_{n+1} = \beta_n + \dot{\beta}_n \Delta t + \ddot{\beta}_n \frac{\Delta t^2}{2}$$

However, since the flapping is periodic in nature and has a direct relationship to the azimuthal angle, PSI, the values for flapping are solved with respects to PSI, vice time. The values of Ω, ψ and time are related by the equation $\Delta\Psi = \Omega \Delta t$. Therefore

$$(6) \quad \dot{\beta} = \frac{d\beta}{dt} = \Omega \frac{d\beta}{d\psi} = \Omega \overset{*}{\beta}$$

$$(7) \quad \ddot{\beta} = \frac{d^2\beta}{dt^2} = \Omega^2 \frac{d^2\beta}{d\psi^2} = \Omega^2 \overset{**}{\beta}$$

The governing equation for the flapping motion now becomes

$$(8) \quad \overset{**}{\beta} = \frac{M_{AERO} + M_W + M_{CF} + M_{EHR}}{I_b \Omega^2}$$

The flapping solution is based on the assumption that the angle of attack is known. However, it is not and the program must proceed through an iterative process in order to determine the inflow ratio, collective pitch and cyclic input angles required to generate the desired forces.

B. ANGLE OF ATTACK CALCULATIONS

A very important and basic part of this program is the procedure by which the local angles of attack are calculated. While the program will calculate angle of attack with any angular velocity applied either to the rotor system or the helicopter, the development here will describe level flight only. The classical approach ignores radial flow, UR, and the angle of attack would be obtained as shown in Figure 1. However, as the blade rotates about the shaft, it will encounter a large variation in radial flow. The program attempts to compensate for this radial flow in the following manner. Instead of the inflow angle PHI equalling the arctangent of UP/UT, it is set equal to UP/UTUR where UTUR is the resultant velocity in the tangential and radial direction. This is illustrated in Figure 3. The pitch angle is also reduced by the cosine of the sweep angle. The angle of attack is now calculated in the sweep plane. This three-dimensional angle of attack is lower than the classical two-dimensional angle.

The program enters the CL, CD tables with this sweep plane angle of attack and the sweep plane resultant Mach number. The program computes the forces using the velocites in the sweep plane, UP and UTUR, and the blade chord geometry in the normal plane. Once the forces are computed in the sweep plane they are resolved into their respective directional forces.

This three-dimensional angle of attack, due to sweep, will delay stall on the rotor by reducing the angle of attack. This describes what actually occurs on the blade. However, it is felt by previous personnel using the program that there is a point where the sweep becomes so large that it tends to wash out the lift being produced. The program has been modified to reduce CL by one half for sweep angles between 60 to 72.5 degrees and reduce CL to zero for sweep angles between 72.5 and 90 degrees. These high sweep angles occur normally only on the inboard blade segments of the

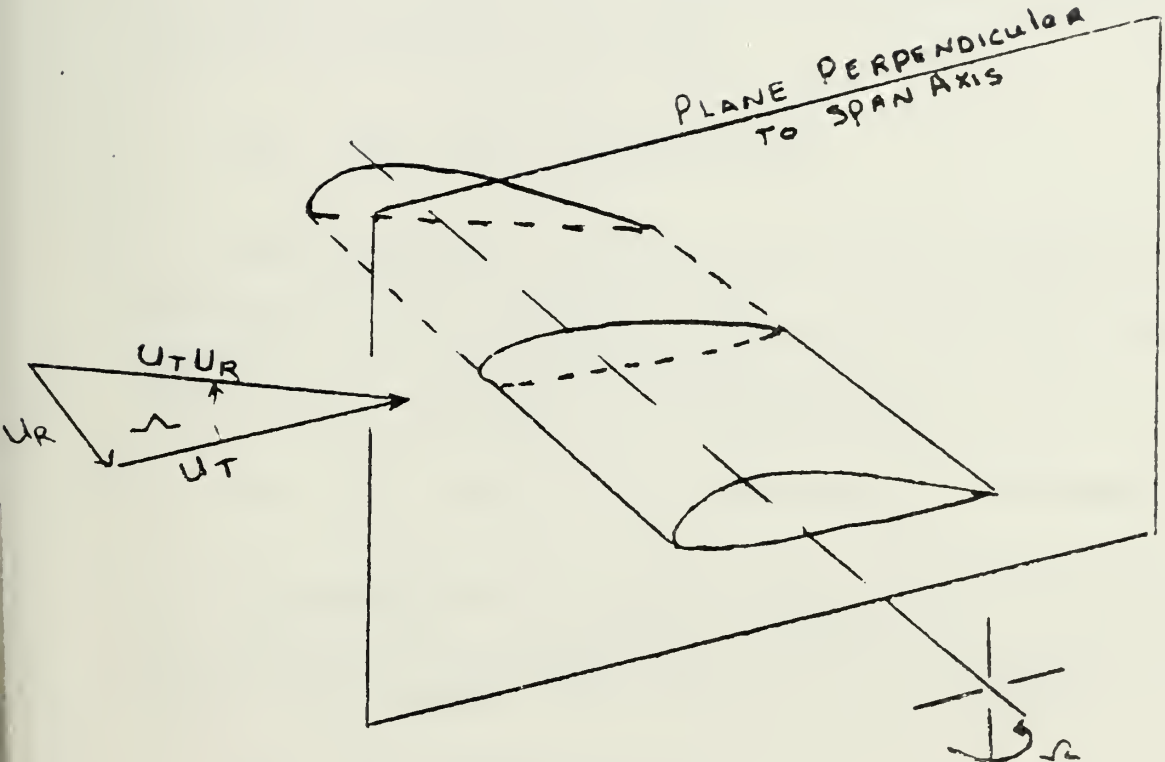


Figure 3 Spanwise Flow Diagram

retreating blade in and near the reverse flow region.

UP, UT, UR and pitch angle for level flight are shown in Figures 4 and 5. They are calculated in the following manner. The radial velocity, UR, is calculated as

$$(9) \quad UR = (V\cos\alpha_s)\cos\Psi\cos\beta$$

The tangential velocity, UT, has two components. The first is the local rotational velocity, Ωr, the second is a sinusodial component of the forward flight velocity. The general expression for UT is

$$(10) \quad UT = \Omega r + (V\cos\alpha_s)\sin\Psi$$

This expression contains a small angle assumption in the term Ωr for blade flapping angle. The program accounts for the fact that the flapping angle does reduce the true radius slightly by using the following formula

$$(11) \quad UT = (E/R + (r - E/R)\cos\beta)\Omega + (V\cos\alpha_s)\sin\Psi$$

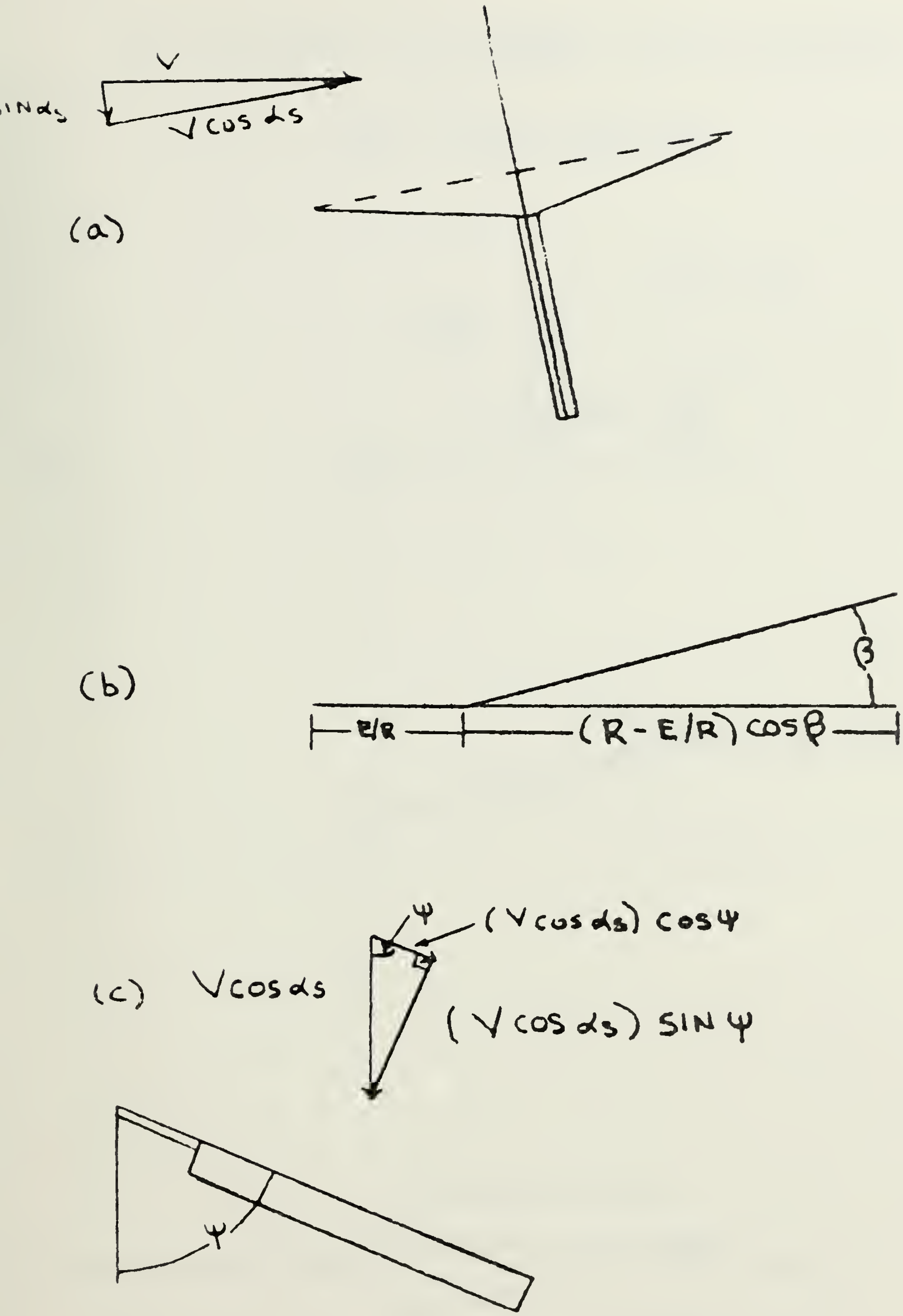
The perpendicular velocity, UP, consists of three terms, the inflow ratio, a flapping velocity and a small component cf forward velocity. The inflow ratio is defined as

$$(12) \quad \lambda = \frac{V\sin\alpha_s - v}{R}$$

The second component is a verical flapping velocity which is a function of flapping rate and radius. This is computed as

$$(13) \quad UP(2) = (r - E/R)\dot{\beta}$$

The third component is due to the fact that there is a small component of the radial flow which acts in the UP direction due to blade flap angle. This is equal to



$$UT = (E/R + (r - E/R)\cos\beta)\Omega + (V\cos\alpha_s)\sin\psi$$

Figure 4 UT Diagram

$$UP = \lambda\Omega R\cos\beta + (r - E/R)\dot{\beta} + (V\cos\alpha_s)\cos\Psi\sin\beta$$

$$UR = (V\cos\alpha_s)\cos\Psi\cos\beta$$

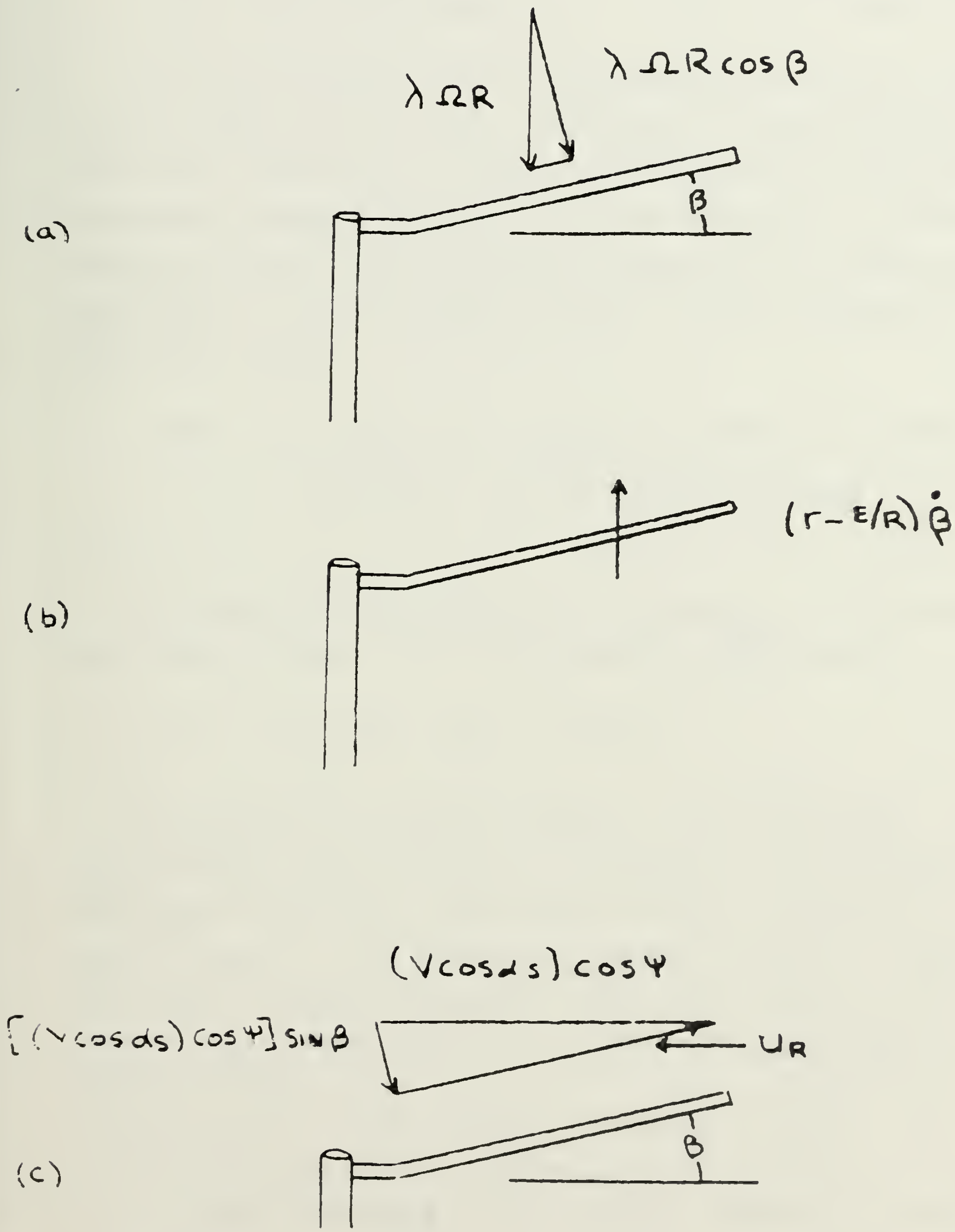


Figure 5 UP and UR Diagram

(14) $UP(3) = (V\cos\alpha_s)\cos\Psi \sin\beta$

The total formula for UP is

(15) $UP = \lambda\Omega R\cos\beta + (r - E/R)\dot{\beta} + (V\cos\alpha_s)\cos\Psi\sin\beta$

The pitch angle (θ) is expressed in equation 16. $\theta.75$ is the pitch angle at the 75 percent radius position, θ' is the twist depending on the relationship of the location of the blade segment to the r = .75R location. The next four terms are the first and second harmonics of cyclic pitch and $(\tan\delta_3)\beta$ is the coupled effect of the flapping angle on the pitch angle.

(16) $\theta = (\theta_{.75} + \theta' - A1S\cos\Psi - B1S\sin\Psi - A2S\cos 2\Psi$
$- B2S\sin 2\Psi - \tan(\delta_3)\,\beta)\cos\Lambda_{sweep}$

The local Mach number is calculated as U/a where a is the speed of sound and U is given in equation 17.

(17) $U = (UP^2 + UT^2 + UR^2)^{1/2}$

The angle of attack can now be calculated. Figure 1 illustrates that $\alpha = \theta - \phi$. Initially, the program requires estimated values for the inflow ratio, collective pitch at the PSI equal zero position, harmonic cyclic inputs, blade twist and initial flapping angle and rate. The user can either input these values or accept the program's automatic default values of -.02, 5, -1.2, 7.53, 0, 0 and 0 respectively. Using these assummed values, the initial angle of attack can be determined as follows.

$UP = \lambda\Omega R\cos\beta + (r - E/R)\dot{\beta} + (V\cos\alpha_s)\cos\Psi\sin\beta$

reduces to

$UP = \lambda\Omega R$

$$UT = (E/R + (r - E/R)\cos\beta)\Omega + (V\cos\alpha_s)\sin\Psi$$

reduces to

$$UT = (E/R + (r - E/R))\Omega$$

$$UR = (V\cos\alpha_s)\cos\Psi\cos\beta$$

reduces to

$$UR = V\cos\alpha_s$$

In the program $V\cos\alpha_s$ is replaced by the term $\mu\Omega R$ where μ is the advance ratio in the shaft axis system. Since the local pitch distribution and inflow ratio are estimated, the local angles of attack can be determined. The next section describes the method used for calculating flapping angle and rates at the N + 1 azimuthal position.

C. METHOD OF SOLUTION FOR THE FLAPPING EQUATION

In the preceding section, equation 8 was developed in order to calculate the time history of the flapping motion.

$$(8) \qquad \overset{**}{\beta} = \frac{M_{AERO} + M_W + M_{CF} + M_{EHR}}{I_b\,\Omega^2}$$

The relation involves a complicated second order differential equation for establishing the flapping angle as a function of PSI. The numberical solution is accomplished by use of a finite difference equation and a step-by-step procedure. An important characteristic of the solution is that it is periodic in nature. The function which represents a steady state flapping solution has the property $\beta(\Psi) = \beta(\Psi + 2\pi)$. Using this fact, a Fourier harmonic series can be written to describe the blade flapping motion.

$$(18) \qquad \beta = A0 - A1\cos\Psi - B1\sin\Psi - A2\cos2\Psi - B2\sin2\Psi - A3\cos3\Psi - B3\sin3\Psi \;\ldots.$$

By assuming that the first harmonic flapping is much larger

than the other higher harmonics, the series can be reduced to

(19) $\beta = A0 - A1\cos\Psi - B1\sin\Psi$

This equation can be differentiated with respect to PSI to obtain

(20) $\overset{*}{\beta} = A1\sin\Psi - B1\cos\Psi$

(21) $\overset{**}{\beta} = A1\cos\Psi - B1\sin\Psi$

Assuming that the values of β , $\overset{*}{\beta}$ and $\overset{**}{\beta}$ are known at some azimuthal position, the following equations must hold

(22) $\beta_n = A0 - A1\cos\Psi - B1\sin\Psi$

(23) $\overset{*}{\beta}_n = A1\sin\Psi - B1\cos\Psi$

(24) $\overset{**}{\beta}_n = A1\cos\Psi + B1\sin\Psi$

These equations can be solved for the N + 1 azimuthal position by substituting $\Psi_{n+1} = \Psi_n + \Delta\Psi$ into the above formulas. The flapping angle equation becomes

(25) $\beta_{n+1} = A0 - A1\cos(\Psi_n + \Delta\Psi) - B1\sin(\Psi_n + \Delta\Psi)$

By using the following two identities equation (25) can be rewritten as equation (28).

(26) $\cos(\Psi_n + \Delta\Psi) = \cos\Psi_n\cos\Delta\Psi - \sin\Psi_n\sin\Delta\Psi$

(27) $\sin(\Psi_n + \Delta\Psi) = \sin\Psi_n\cos\Delta\Psi + \cos\Psi_n\sin\Delta\Psi$

(28) $\beta_{n+1} = A0 - A1(\cos\Psi_n\cos\Delta\Psi - \sin\Psi_n\sin\Delta\Psi)$
$\quad - B1(\sin\Psi_n\cos\Delta\Psi - \cos\Psi_n\sin\Delta\Psi)$

The terms can be rearranged into equation 29. The same procedure can be used to develop equation 30 for $\overset{*}{\beta}$.

(29) $\beta_{n+1} = A0 - \cos\Delta\Psi(A1\cos\Psi_n + B1\sin\Psi_n)$
$\quad + \sin\Delta\Psi(A1\sin\Psi_n - B1\cos\Psi_n)$

(30) $\overset{*}{\beta}_{n+1} = \cos\Delta\Psi(A1\sin\Psi_n - B1\cos\Psi_n)$
$\quad + \sin\Delta\Psi(A1\cos\Psi_n + B1\sin\Psi_n)$

Substitution into equations 22, 23 and 24 reduces these two

expressions to the flapping equations used in the program. The user can either enter the value for $\Delta\Psi$ or accept the programs automatic default value of 15 degrees.

$$(31) \quad \overset{*}{\beta}_{n+1} = \overset{*}{\beta}_n \cos\Delta\Psi + \overset{**}{\beta}_n \sin\Delta\Psi$$

$$(32) \quad \beta_{n+1} = \beta_n + \overset{*}{\beta}_n \sin\Delta\Psi + (1-\cos\Delta\Psi)\,\overset{**}{\beta}_n$$

While this integration scheme is not one of the standard methods used, it is very useful in obtaining periodic solutions for differential equations similar to the one used here. Notice that for small values of $\Delta\Psi$ the trignometric expression can be reduced to an ordinary Taylor series. By assuming $\sin\Delta\Psi$ equals $\Delta\Psi$ and $\cos\Delta\Psi$ equals one equation 29 reduces to

$$(33) \quad \overset{*}{\beta}_{n+1} = \overset{*}{\beta}_n + \Delta\Psi\,\overset{**}{\beta}_n$$

By assuming $\sin\Delta\Psi$ equals $\Delta\Psi$ and $\cos\Delta\Psi$ equals the first two terms of the cosine series $1 - \frac{\Delta\Psi^2}{2}$ equation 32 can be reduced to

$$(34) \quad \beta_{n+1} = \beta_n + \Delta\Psi\,\overset{*}{\beta}_n + \frac{1}{2}(\Delta\Psi)^2\,\overset{**}{\beta}_n$$

D. FORCES, MOMENTS AND RADIAL INTEGRATION

The forces acting on a rotor blade may be found by the summation of the elementry forces along the span at any azimuthal position. The forces considered by the program are the resulting aerodynamic forces only, and are initially summed in the shaft reference axis system. The program computes forces in three axis systems. They are the (1) shaft, (2) control and (3) relative wind axis systems.

The program radially integrates differently for lift and drag calculations. The drag is calculated from the hinge offset, E/R, to the rotor tip. The lift is calculated from

the hinge offset to the next to last rotor blade segment. The last segment is considered a blade "Tip Loss Factor" segment. It is assumed that the tip trailing edge vortices cause no lift to be produced in this segment. The normal procedure is to define this segment as the last three percent of the rotor blade radius.

The first of the maximum 15 blade segments is considered the spar or cut out segment. This is defined as the area between the hinge offset and the point where the airfoil actually begins. If no spar data are entered, it is asssumed that this first segment produces no lift and drag is obtained by using the CD verse Alpha Tables for the first blade airfoil data deck entered. If spar data are entered, the first segment and all other segments designated spar segments will have the lift and drag characteristics of the entered spar data.

E. AZIMUTHAL INTEGRATION METHOD

Once the integration of the rotor forces and moments along the blade is complete, an integration around the azimuth must be performed in order to obtain the average forces and moments. Since the solution of the flapping equation is obtained by a step-by-step method, the integrands of the integrals over Ψ are known only at a certain number of equally spaced points around the azimuth. For equilibrium flapping the integral is a periodic function of Ψ, and for this case integration can be shown to be equivalent to an averaging process. This result makes the azimuthal integration simple. The following method is used where N is the number of azimuthal positions used in the calculations and b is the number of blades.

$$(35) \quad \frac{b}{2\pi}\int_0^{2\pi}\int_0^{R} F(x,\Psi)\,dx\,d\Psi = \frac{b}{N}\sum_{i=1}^{N}\sum_{j=1}^{K} dF(\Psi_{ij})$$

F. MAJOR ITERATION

Once the program has calculated a steady state flapping solution and has determined the resulting forces and moments, a question remains to be answered. Is this the desired solution and, if not, what must be done to obtain this solution? In order to solve the flapping equations certain known or assumed values were used, including inflow ratio (λ), collective pitch (θ.75) and the cyclic pitch (A1S, B1S, A2S and B2S). One method, first described in Ref. 3, is to iterate on the required lift and drag through modification of λ and θ.75, where θ.75 is the pitch angle at the 75 percent radius station at the PSI equal zero azimuthal position. The modified values are then reentered into the flapping routine and the calculation is repeated until it converges to within a specified tolerance on the required lift and drag. Drag is used here in the sense of negative rotor propulsive force. The program procedure is outlined below.

The required rotor lift and propulsive force are expressed in terms of the magnitude and direction of the resultant force in the longitudinal plane. These are shown in Figure 6 where it can be seen that

(36) $a'' = \alpha_s + a'$

(37) $R_\ell = \left((F_{z_s})^2 + (F_{x_s})^2 \right)^{1/2}$

(38) $L = R_\ell \cos(a'')$ $\qquad D = R_\ell \sin(a'')$

The required lift and propulsive force and their resultant are shown in Figure 7. In a similar way,

(39) $R = \left(L_R^2 + D_R^2 \right)^{1/2}$

(40) $a'' = \arctan\,(D_R/L_R)$

The differences between the required and the computed R_ℓ and a" values are defined as

(41) $\Delta R_\ell = R_{\ell R} - R_L$

(42) $\Delta a'' = a''_R - a''$

In order to correct λ and $\theta.75$ to compensate for the difference between $(R_{\ell R}, a''_R)$ and (R_ℓ, a''), the required values are expanded in a Taylor series with λ and $\theta.75$ as variables. The first order equations are:

(43) $$R_{\ell R} = R_\ell + \frac{\partial R_\ell}{\partial \lambda}\Delta\lambda + \frac{\partial R_\ell}{\partial \theta_{.75}}\Delta\theta_{.75}$$

(44) $$a''_R = a'' + \frac{\partial a''}{\partial \lambda}\Delta\lambda + \frac{\partial a''}{\partial \theta_{.75}}\Delta\theta_{.75}$$

Solving the equations for the iteration on λ and $\theta.75$ yields

(45) $$\Delta\lambda = \frac{\dfrac{\partial a''}{\partial \theta_{.75}}\Delta R_\ell - \dfrac{\partial R_\ell}{\partial \theta_{.75}}\Delta a''}{\dfrac{\partial R_\ell}{\partial \lambda}\dfrac{\partial a''}{\partial \theta_{.75}} - \dfrac{\partial R_\ell}{\partial \theta_{.75}}\dfrac{\partial a''}{\partial \lambda}}$$

(46) $$\Delta\theta_{.75} = \frac{\dfrac{\partial R_\ell}{\partial \lambda}\Delta a'' - \dfrac{\partial a''}{\partial \lambda}\Delta R}{\dfrac{\partial R_\ell}{\partial \lambda}\dfrac{\partial a''}{\partial \theta_{.75}} - \dfrac{\partial R_\ell}{\partial \theta_{.75}}\dfrac{\partial a''}{\partial \lambda}}$$

Now that $R_{\ell R}$, R_ℓ and a''_R and a" are known, the corrected values of λ and $\theta.75$ can be approximated by:

(47) $$\lambda_N = \lambda + \Delta\lambda \qquad \theta_{.75N} = \theta_{.75} + \Delta\theta_{.75}$$

In order to solve equations 45 and 46, the values of the partial derivatives in these equations must be found. The

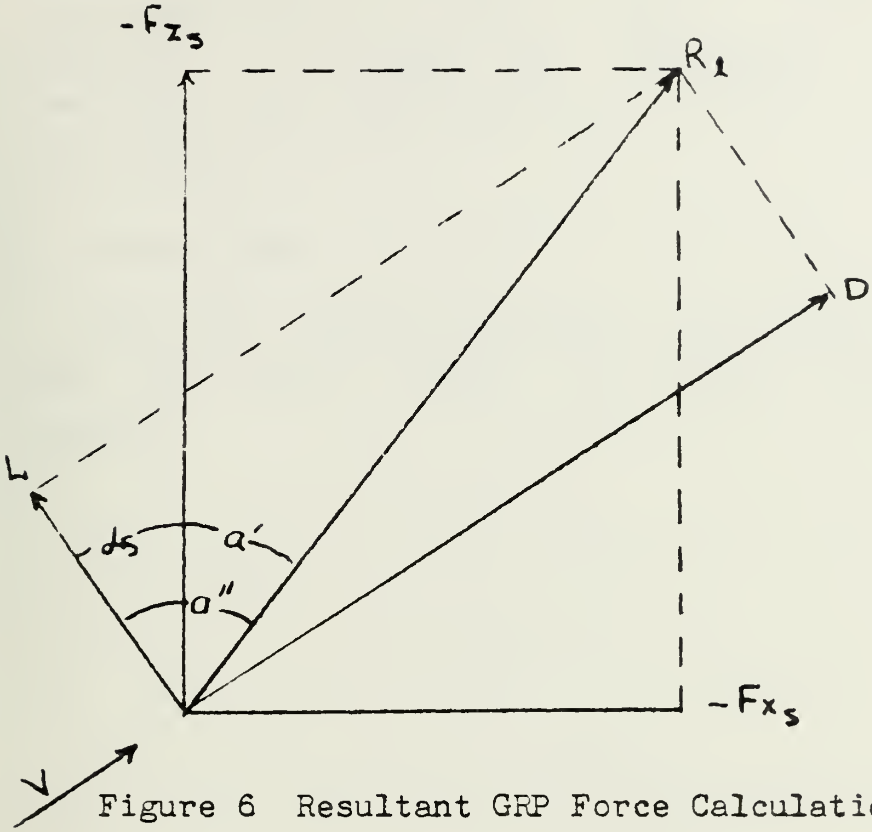


Figure 6 Resultant GRP Force Calculation Diagram

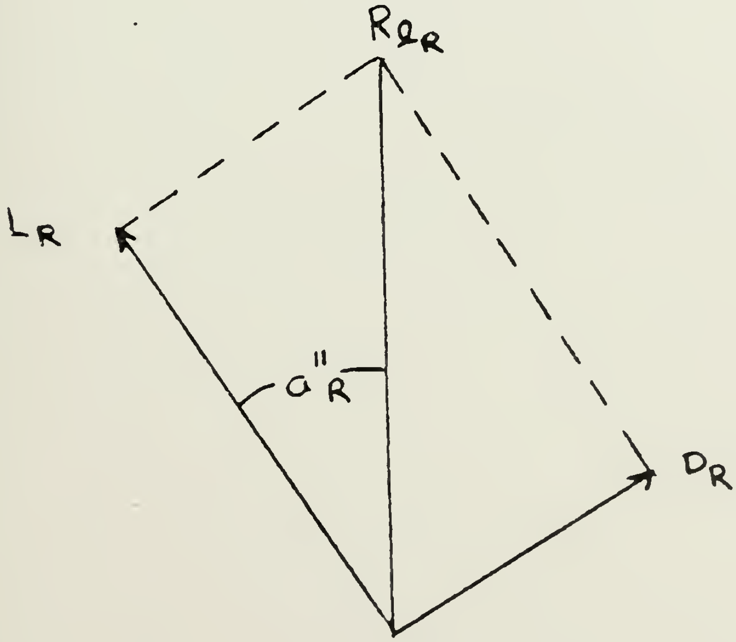


Figure 7 Required GRP Force Diagram

procedure used in based on the Wheatley-Bailey method and the formulas can be found on pages 186 and 207 of Ref. 4. Reference 5 outlines the derivation and a complete derivation was performed and verified in conjunction with this thesis.

G. FLOW CHART

The flow chart in Figure 8 is a block diagram showing the relationship between the various parts of the GRP program.

GRP FLOW CHART

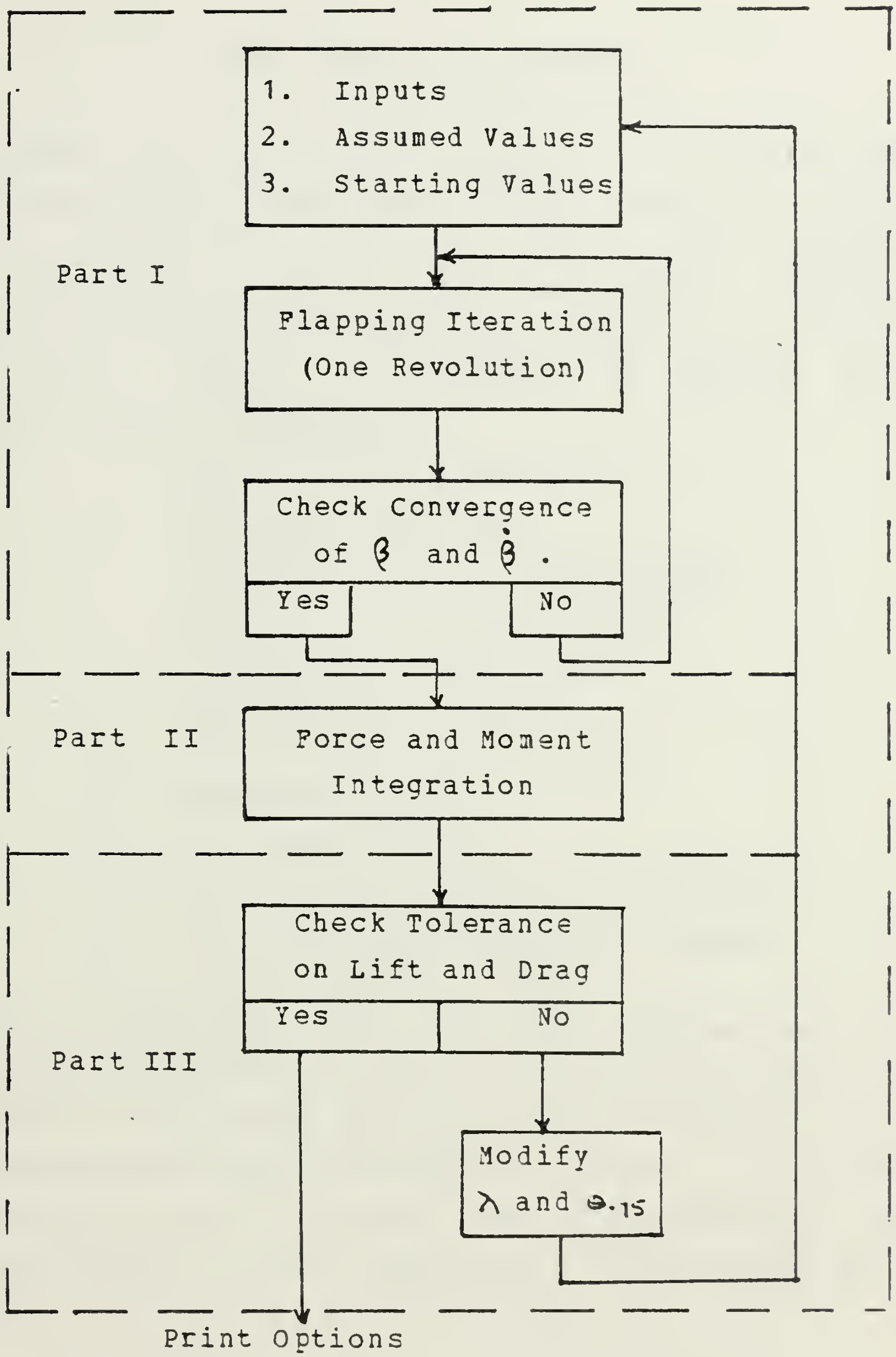


Figure 8

III. GRP USERS' MANUAL

The GRP currently has the capability to enter over 200 individual case variables and option selectors. Presently, 170 are available to the users. This manual explains the input and output format of this GRP program. Examples of both input and output are given in order to make the use of this program easier. This manual is divided into the following areas of discussion.

A. Main Iteration Options
B. GRP Data Deck Order
C. Airfoil Data Deck Requirements
D. Spar Data Deck Requirements
E. Sample Data Input Format
F. Case Input Listings
G. Case Input Default Values
H. Case Input Data
I. Case Input Format
J. Case Optional Output Indicators
K. IBM 360 Execution Control Cards
L. Sample Program Output

It is recommended that the user examine the GRP Case Input listing carefully, since a few options require certain variables to be inputed which are not necessarily located in the same general area of the input listings. An attempt has been made to list all input variables concerned with the different options in the discussion of each option and input variable.

A. MAIN ITERATION OPTIONS

The GRP offers the user six different options for determining a solution. They are as follows.

1. Normal Routine

In the normal solution to the problem the computer will vary the inflow ratio, LAMBDA, and the pitch angle, θ.75, in order to produce the required lift and drag. The cyclic inputs, A1S and B1S, are considered constants. Uniform inflow is assumed unless the user induces a non-uniform inflow by the use of variables 117 and 118, LAML and UVL. The program will calculate the required shaft axis angle and position of the control axis from the fixed value of B1S. In all of the options, the user has a choice of using either a program calculated first estimate of flapping angle, velocity and acceleration or an initial value of zero for all of the above. Either method usually requires the same approximate amount of computer time. The variable PCNV, item 97, determines the method to be used.

2. Desired Flapping Angles

This option allows the user to specify the desired longitundinal and lateral flapping angles with respect to the rotor shaft axis. The program at each intermedient force iteration will vary A1S, B1S, inflow ratio and pitch angle. Variables 100 and 112, 113 and 114 control the use of this option.

3. Short Iteration Scheme

This option follows the normal routine with one major exception. The program will make only one pass through the flapping routine on each major iteration. The program may or may not arrive at a steady state solution for flapping in the first few iterations. It is assumed that the first few iterations in the normal routine are only rough estimates of the way the variables should be changed and that an exact flapping solution is not actually required if the user is only interested in transient flapping

behavior. In order to use this routine, the user must input a negative number for the variable XITLIM, item 73. The absolute value of XITLIM will still determine the maximum allowable number of times the program will enter the major iteration routine.

4. Trimmed Moments

This option will follow the Normal method described in paragraph one. The Normal method will only converge on lift and drag and will not consider the moments produced. If the variable TRIM, item 160, were assigned a non-zero value, the program would attempt to trim out the pitching and rolling moments about the rotor shaft. It is suggested that this be done in a two case run. The first case should be a normal run, with the desired printout. Then, for the second case, input the variable TRIM. This will do two things. First, it will provide a converged solution without consideration of moments. Secondly, it will allow the full number of iterations to be used to reduce the moments. The program does this by a short routine varying A1S and B1S. During this process, the whole flapping and force iterations must be repeated, but it will at least start by using a converged solution. The variable PCNV, item 97, should be non-zero to allow the flapping solution from the previous case to be used as a first estimate in this case. Setting the variable SKIPIN, item 91, equal to zero will allow a force and moment summation to be outputed for each major iteration. This will allow the user to see exactly how the program is proceeding.

5. TOP Option

In this option, the program iterates upon the required lift but ignores any values inputed for required drag. This option can be used to simulate a wind-tunnel test. The user must input the shaft angle, item 111, and

the pitch angle, item 87. These two inputs will be held constant. The program will iterate on the inflow ratio, LAMBDA, in order to obtain a solution. The variable TOP, item 96, controls the use of this option.

6. ALOPT Option

This option, like TOP, is a wind tunnel option. It also iterates on required lift only. However, here the shaft angle, item 111, and the inflow ratio, item 88, are required inputs and are held as constants. The program will iterate on the pitch angle, item 87, in order to determine a solution. The variable ALOPT, item 110, controls the use of this option.

B. GRP DATA DECK ORDER

Data is entered into this program in the following order.

1. Airfoil Lift Coefficient Table
2. Airfoil Drag Coefficient Table
   (Repeat steps one and two as necessary.)
3. Case Input Data
4. Harmonics of the Inflow Ratio **
5. Spar Lift Coefficient Table **
6. Spar Drag Coefficient Table **

** Optional Data

C. AIRFOIL BLADE DECK REQUIREMENTS

The GRP program requires that all CL and CD information be entered into the program in tabular form. Tables for up to 15 different Mach numbers and five different airfoils can be entered. The program currently does not use or require values for the Coefficient of Moment, CM. Since certain segments of the retreating blade are in the reverse flow region, angle of attack tables are required to include

valued from -180 degrees to +180 degrees. If they are not included, an error message will be printed when the program can not locate a value for CL and CD at these large positive and negative angles of attack. If complete angle of attack information is not available for a particular airfoil, the user can use the values provided in Section E. It is realized that available data on airfoil behavior at large angles of attack are very limited, but so is the region on the rotor disc where the blade operates at these high angles. Since this occurs only immediately around and within the reverse flow region where dynamic pressure is low, little precision is lost in performance calculation by using one common representation for most airfoil behavior.

As a minimum, two values for CL and CD at two different angles of attack and Mach numbers must be supplied. As a maximum, 15 different values of Mach number may be entered. Each Mach number may contain up to 48 different values of CL and 48 different values of CD and their associated angles of attack.

The first Mach number must be equal to zero. This table can be an exact duplicate of the lowest Mach number table the user has available. The highest Mach number table should be high enough in order to prevent the program from stopping because of a local Mach number higher than that in the table. A quick check can be obtained by adding together the rotor tip velocity and the forward flight speed. This combined velocity, divided by the local speed of sound, must be less than the maximum Mach number entered into the program. The program linearly interpolates between Mach numbers and angles of attack in order to determine the value of CL and CD. The subroutine BLIN4 does the interpolation.

Several options are available to help reduce the number of data points that must be entered. If the airfoil is symmetrical, the user only needs to enter values for positive angles of attack. The program will assign the

appropiate sign to the value of CL and CD according to the sign of the angle of attack. This is accomplished by case input variable 107, SYM. This option can also be used for a cambered airfoil where values of CL and CD at negative angles of attack are unknown.

Values for large angles of attack need not be entered for each Mach number by making use of the program's input variables 156 and 157, or their automatic default values. Values for large positive and negative angles of attack need only be entered for the two lowest Mach number tables. The lowest Mach number table must be at a Mach number equal to zero. If an angle of attack is greater than variable 156 (HIALFA) or lower than variable 157 (LOALFA), or the programs default values of plus and minus 30 degrees, the Mach number is set equal to zero. This ensures that only the first two Mach numbers have to carry the whole range of angles of attack from -180 to +180 degrees for a cambered airfoil or from zero to +180 degrees for a symmetrical airfoil.

The format of the table input will now be described. The first data card contains the variable WBLADE. This controls whether or not the user receives an echo printout of the Blade Airfoil Data being entered. If the value of WBLADE is equal to zero, the user will not receive an echo printout of the Blade Data. If WBLADE is a non-zero number, the user will receive the echo printout. The read format for WBLADE is F10.0. WBLADE is the only item on the first data card.

The next card also contains only one piece of data, NBLADE. NBLADE is the number of different airfoil data sets to be used and appears on this card in an I2 format. This program will accept up to five different blade airfoil data sets. It will also accept one blade spar data set. If the rotor blade being analyzed were composed of three different types of airfoils, NBLADE would equal three. However, if

the blade consisted of three sections, of which the first and third section were the same, NBLADE would equal two. It is explained later how the blade segments are assigned their respective airfoil type. This arrangement provides the user with the ability to vary the make-up of the blade while only having to enter into the program once a particular set of airfoil data.

The above two variables, WBLADE and NBLADE, are only entered once for each complete computer run which uses the same set of airfoil data. The following information will be entered twice for each type of airfoil used. It will be entered first for CL and secondly for CD for each type airfoil. The overall format is summarized below.

Card 1	WBLADE
Card 2	NBLADE
Card 3-	CL's for airfoil number one
	CD's for airfoil number one
	CL's for airfoil number two
	CD's for airfoil number two
	Repeat as necessary.

Card number three contains the variable NZ, which is the number of Mach numbers for which CL's will be entered for the first airfoil. This number must be right justified in I2 format. The maximum number of Mach numbers for each CL and CD for one airfoil is 15. This is the only number entered on this card.

Card number four begins the actual Mach number, CL versus angle of attack tables. The format in this paragraph must be repeated for each Mach number. This first card is divided into 11 fields (I2, 10F7.0). The first field is a two-digit, right-justified integer in I2 format. It is equal to twice the number of data pairs for this Mach number plus two. This tells the computer how many numbers are required to be entered for this particular Mach number. A data pair consist of one angle of attack and its associated

CL or CD. The remaining ten fields are each seven columns long in floating point or F7.0 format. These fields begin in columns 3, 10, 17, 24, 31, 38, 45, 52, 59, and 66. On this first card, the field that starts in column three contains the number of data pairs at this Mach number. The field that begins in columns 10 is the actual Mach number. The remaining eight fields on this card are for the first four data pairs starting with the lowest angle of attack and increasing towards the highest angle of attack. If a symmetrical airfoil option is used, the lowest angle of attack is zero. If a non-symmetrical airfoil is used, the lowest value for the first two Mach numbers should be -180 degrees and for all the remaining Mach numbers the value of LOMACH entered or -30 degrees.

All the remaining cards for this particular Mach number will contain the data pairs. These cards contain ten fields each, the first field consisiting of nine columns and the remaining nine fields consist of seven columns beginning in column ten and following the same format as the first card. The format is (F9.0, 9F7.0). This card is repeated as often as needed. Columns 73-80 are not read and may be used for comments.

This procedure is repeated until all the CL's are entered. Once completed the program is ready to enter the values for CD. The whole procedure is repeated again, starting with the value for NZ representing the number of Mach numbers for which CD's will be entered. If more than one airfoil data deck is to be used, the above procedure will start over again by reading in the value of NZ for the number of Mach numbers to be entered for values of CL for the second airfoil. The number of data pairs for each Mach number must be between 2 and 48. The number of "twice the data pairs plus two" must be between 6 and 98.

Prior to entering the airfoil data, the user should review the following input variables.

1. SYM (107) - Symmetrical and nonsymmetrical airfoil data input control.
2. HIALFA (156) - The highest angle of attack for which values of CL and CD will be found at all Mach numbers.
3. LOAFLA (157) - The lowest angle of attack for which values of CL and CD will be found at all Mach numbers.
4. SPAR (103) - Number of segments using spar airfoil data.
5. TIPSWP (158) - Amount of tip sweep in degrees.
6. TPSWST (159) - Blade segment number at which the tip sweep begins.
7. BSPL (120) - Input control variable for spar data.
8. RB(I) (161-175) - Controls the blade segment airfoil data assignment.

D. SPAR DATA DECK REQUIREMENTS

The format for spar data are similar to that of the airfoil data with the exception that only one set of spar data can be entered into the program. Before the program will read spar data, input variable number 120, BSPL, must have a non-zero value. In addition, variable 103, SPAR, must indicate the number of blade segments which are using the spar data. The program automatically assumes that the first segment is a spar segment. This is further explained in the Case Input section. The spar data are the last to be entered into the program. This is an optional input and is not required. If spar data are not inputed, the program will assume that the one automatic spar section creates no lift and has the drag characteristics of the first airfoil section entered.

The format for inputing spar data are as follows. The first card contains the variable WRSPAR in F10.0 format. A non-zero value of WRSPAR causes an echo printout of spar data to occur. The remaining spar data are handled the exact same way as the airfoil section data, starting with the variable NZ. There is no input similar to that of the airfoil section stating how many different spar data decks are being entered since only one is allowed. As before, a minimum of two Mach numbers are required to be entered. The blade segment printout indicates spar segments by the use of a "0" for that segment.

Input variables associated with SPAR data are as follows.

1. SPAR (103) - The number of blade segments using spar data.
2. BSPL (120) - Input variable which controls the input and use of spar data.

E. SAMPLE BLADE INPUT

The next several pages illustrates the sample format for a blade which has the following characteristics: (1) an echo printout is not required, (2) there are two airfoil decks to be read in and (3) the first airfoil deck has nine values of Mach numbers for which CL's are to be entered.

0. 2 9									
98 48.	0.	-180.	0.	-172.	.8	-166.	.8	-160.	.66
-158.	.68	-148.	1.0	-142.	1.08	-130.	1.0	-60.	-1.0
-50.	-1.09	-40.	-1.09	-30.	-1.01	-22.	-.98	-20.	-.975
-18.	-.969	-16.	-.963	-14.	-1.07	-12.	-.718	-10.	-.366
-8.	-.245	-6.	-.390	-4.	-.4	-2.	-.185	0.	.029
2.	.244	4.	.459	6.	.673	8.	.883	10.	1.103
12.	1.25	14.	1.1	16.	.99	18.	.982	20.	.984
22.	.987	30.	1.01	40.	1.09	50.	1.09	60.	1.0
132.	-1.	140.	-1.06	142.	-1.06	148.	-1.	158.	-.68
160.	-.66	166.	-.8	172.	-.8	180.	0.		
98 48.	0.3	-180.	0.	-172.	.8	-166.	.8	-160.	.66
-158.	.68	-148.	1.0	-142.	1.08	-130.	1.0	-60.	-1.0
-50.	-1.09	-40.	-1.09	-30.	-1.01	-22.	-.98	-20.	-.975
-18.	-.969	-16.	-.963	-14.	-1.07	-12.	-.718	-10.	-.366
-8.	-.245	-6.	-.390	-4.	-.4	-2.	-.185	0.	.029
2.	.244	4.	.459	6.	.673	8.	.883	10.	1.103
12.	1.25	14.	1.1	16.	.99	18.	.982	20.	.984
22.	.987	30.	1.01	40.	1.09	50.	1.09	60.	1.0
132.	-1.	140.	-1.06	142.	-1.06	148.	-1.	158.	-.68
160.	-.66	166.	-.8	172.	-.8	180.	0.		
48 23.	0.4	-22.	-.96	-20.	-.96	-18.	-.962	-16.	-.966
-14.	-.824	-12.	-.532	-10.	-.24	-8.	-.3	-6.	-.44
-4.	-.42	-2.	-.185	0.	.048	2.	.282	4.	.515
6.	.749	8.	.983	10.	1.17	12.	1.13	14.	1.03
16.	.98	18.	.986	20.	.972	22.	.979		
48 23.	0.5	-22.	-.914	-20.	-.91	-18.	-.906	-16.	-.902
-14.	-.803	-12.	-.528	-10.	-.4	-8.	-.33	-6.	-.32
-4.	-.44	-2.	-.196	0.	.048	2.	.292	4.	.536
6.	.78	8.	.96	10.	1.01	12.	.96	14.	1.07
16.	1.06	18.	1.07	20.	1.065	22.	1.06		
48 23.	0.6	-22.	-.934	-20.	-.93	-18.	-.926	-16.	-.922
-14.	-.805	-12.	-.66	-10.	-.61	-8.	-.55	-6.	-.52
-4.	-.47	-2.	-.199	0.	.072	2.	.343	4.	.614
6.	.84	8.	.91	10.	.946	12.	1.0	14.	1.053
16.	1.075	18.	1.064	20.	1.053	22.	1.042		
48 23.	0.7	-22.	-.926	-20.	-.92	-18.	-.914	-16.	-.908
-14.	-.880	-12.	-.83	-10.	-.78	-8.	-.74	-6.	-.68
-4.	-.58	-2.	-.255	0.0	.07	2.	.395	4.	.72
6.	.83	8.	.882	10.	.92	12.	.924	14.	.928
16.	.92	18.	.9	20.	.9	22.	.92		
48 23.	0.8	-22.	-.875	-20.	-.856	-18.	-.838	-16.	-.819
-14.	-.8	-12.	-.79	-10.	-.81	-8.	-.75	-6.	-.69
-4.	-.47	-2.	-.25	0.0	.07	2.	.35	4.	.56
o.	.705	8.	.805	10.	.842	12.	.845	14.	.848
16.	.860	18.	.88	20.	.9	22.	.92		

48 23.	0.9	-22.	-.838	-20.	-.81	-18.	-.782	-16.	-.754
-14.	-.726	-12.	-.698	-10.	-.67	-8.	-.666	-6.	-.663
-4.	-.486	-2.	-.31	0.0	-.15	2.	.138	4.	.39
6.	.64	8.	.785	10.	.81	12.	.829	14.	.848
16.	.887	18.	.886	20.	.905	22.	.924		
48 23.	1.0	-22.	-.822	-20.	-.79	-18.	-.758	-16.	-.726
-14.	-.694	-12.	-.662	-10.	-.63	-8.	-.622	-6.	-.615
-4.	-.428	-2.	-.24	0.0	-.05	2.	.2	4.	.449
6.	.7	8.	.806	10.	.85	12.	.865	14.	.88
16.	.895	18.	.91	20.	.925	22.	.94		
09									
96 47.	0.0	-180.	.02	-165.	.2	-155.	.4	-140.	1.0
-120.	1.6	-115.	1.8	-100.	1.95	-90.	2.0	-80.	1.95
-67.	1.8	-43.	1.2	-30.	.6	-22.	.3438	-20.	.2723
-18.	.2007	-16.	.1293	-14.	.0576	-12.	.0174	-10.	.008
-8.	.0082	-6.	.0079	-4.	.0075	-2.	.0075	0.0	.0075
2.	.008	4.	.0085	6.	.009	8.	.011	10.	.017
12.	.026	14.	.145	16.	.2147	18.	.274	20.	.3333
22.	.2927	30.	.6	43.	1.2	67.	1.8	80.	1.95
90.	2.0	100.	1.95	115.	1.8	120.	1.6	140.	1.0
155.	.4	165.	.2	180.	.02				
96 47.	0.3	-180.	.02	-165.	.2	-155.	.4	-140.	1.0
-120.	1.6	-115.	1.8	-100.	1.95	-90.	2.0	-80.	1.95
-67.	1.8	-43.	1.2	-30.	.6	-22.	.3438	-20.	.2723
-18.	.2007	-16.	.1293	-14.	.0576	-12.	.0174	-10.	.008
-8.	.0082	-6.	.0079	-4.	.0075	-2.	.0075	0.0	.0075
2.	.008	4.	.0085	6.	.009	8.	.011	10.	.017
12.	.026	14.	.145	16.	.2147	18.	.274	20.	.3333
22.	.2927	30.	.6	43.	1.2	67.	1.8	80.	1.95
90.	2.0	100.	1.95	115.	1.8	120.	1.6	140.	1.0
155.	.4	165.	.2	180.	.02				
48 23.	.4	-22.	.3885	-20.	.3281	-18.	.2678	-16.	.2073
-14.	.147	-12.	.0225	-10.	.0132	-8.	.0095	-6.	.0085
-4.	.008	-2.	.008	0.	.008	2.	.0082	4.	.0085
6.	.0105	8.	.014	10.	.021	12.	.0935	14.	.1635
16.	.225	18.	.2836	20.	.3414	22.	.3991		
48 23.	0.5	-22.	.4065	-20.	.3506	-18.	.2948	-16.	.2388
-14.	.183	-12.	.12	-10.	.068	-8.	.0206	-6.	.0097
-4.	.008	-2.	.0075	0.0	.0075	2.	.0075	4.	.008
6.	.011	8.	.026	10.	.08	12.	.153	14.	.2121
16.	.2643	18.	.3166	20.	.3688	22.	.421		
48 23.	0.6	-22.	.414	-20.	.36	-18.	.3267	-16.	.2887
-14.	.246	-12.	.191	-10.	.127	-8.	.07	-6.	.026
-4.	.0125	-2.	.0085	0.	.008	2.	.0075	4.	.011
6.	.029	8.	.0743	10.	.1247	12.	.18	14.	.246
16.	.2887	18.	.3267	20.	.36	22.	.414		
48 23.	0.7	-22.	.458	-20.	.415	-18.	.372	-16.	.329
-14.	.286	-12.	.243	-10.	.177	-8.	.113	-6.	.06
-4.	.03	-2.	.012	0.	.008	2.	.0105	4.	.036

6.	.061	8.	.126	10.	.162	12.	.238	14.	.284
16.	.329	18.	.372	20.	.415	22.	.458		
48 23.	0.8	-22.	.479	-20.	.441	-18.	.403	-16.	.3655
-14.	.3278	-12.	.29	-10.	.225	-8.	.16	-6.	.1
-4.	.065	-2.	.028	0.	.017	2.	.04	4.	.09
6.	.128	8.	.17	10.	.225	12.	.285	14.	.328
16.	.3655	18.	.403	20.	.441	22.	.479		
48 23.	0.9	-22.	.497	-20.	.463	-18.	.43	-16.	.397
-14.	.363	-12.	.33	-10.	.262	-8.	.203	-6.	.149
-4.	.115	-2.	.066	0.	.05	2.	.08	4.	.12
6.	.167	8.	.21	10.	.262	12.	.3225	14.	.357
16.	.391	18.	.43	20.	.463	22.	.497		
48 23.	1.0	-22.	.514	-20.	.486	-18.	.457	-16.	.428
-14.	.399	-12.	.37	-10.	.297	-8.	.248	-6.	.202
-4.	.152	-2.	.117	0.	.09	2.	.1175	4.	.1525
6.	.203	8.	.249	10.	.298	12.	.363	14.	.393
16.	.423	18.	.457	20.	.486	22.	.514		
9									
98 48.	0.	-180.	0.	-172.	.8	-166.	.8	-160.	.66
-158.	.68	-148.	1.0	-142.	1.08	-130.	1.0	-60.	-1.0
-50.	-1.09	-40.	-1.09	-30.	-1.01	-22.	-.98	-20.	-.975
-18.	-.689	-16.	-.403	-14.	-.278	-12.	-.242	-10.	-.72
-8.	-.63	-6.	-.49	-4.	-.29	-2.	-.07	0.	.15
2.	.37	4.	.59	6.	.81	8.	1.03	10.	1.25
12.	1.38	14.	1.5	16.	1.55	18.	1.072	20.	1.04
22.	1.032	30.	1.01	40.	1.09	50.	1.09	60.	1.0
132.	-1.	140.	-1.06	142.	-1.06	148.	-1.	158.	-.68
160.	-.66	166.	-.8	172.	-.8	180.	0.		
98 48.	0.3	-180.	0.	-172.	.8	-166.	.8	-160.	.66
-158.	.68	-148.	1.0	-142.	1.08	-130.	1.0	-60.	-1.0
-50.	-1.09	-40.	-1.09	-30.	-1.01	-22.	-.98	-20.	-.975
-18.	-.689	-16.	-.403	-14.	-.278	-12.	-.242	-10.	-.72
-8.	-.63	-6.	-.49	-4.	-.29	-2.	-.07	0.	.15
2.	.37	4.	.59	6.	.81	8.	1.03	10.	1.25
12.	1.38	14.	1.5	16.	1.55	18.	1.072	20.	1.04
22.	1.032	30.	1.01	40.	1.09	50.	1.09	60.	1.0
132.	-1.	140.	-1.06	142.	-1.06	148.	-1.	158.	-.68
160.	-.66	166.	-.8	172.	-.8	180.	0.		
48 23.	0.4	-22.	-.775	-20.	-.65	-18.	-.527	-16.	-.47
-14.	-.28	-12.	-.343	-10.	-.48	-8.	-.52	-6.	-.47
-4.	-.27	-2.	-.047	0.	.176	2.	.399	4.	.622
6.	.845	8.	1.068	10.	1.27	12.	1.32	14.	1.078
16.	1.074	18.	1.07	20.	1.058	22.	1.046		
48 23.	0.5	-22.	-.827	-20.	-.765	-18.	-.704	-16.	-.642
-14.	-.58	-12.	-.57	-10.	-.56	-8.	-.53	-6.	-.49
-4.	-.295	-2.	-.085	0.	.141	2.	.384	4.	.627
6.	.87	8.	1.03	10.	1.07	12.	1.1	14.	1.117
16.	1.13	18.	1.07	20.	1.064	22.	1.058		
48 23.	0.6	-22.	-.84	-20.	-.773	-18.	-.707	-16.	-.64

-14.	-.573	-12.	-.522	-10.	-.488	-8.	-.453	-6.	-.418
-4.	-.315	-2.	-.11	0.	.145	2.	.425	4.	.72
6.	.89	8.	.939	10.	.976	12.	1.013	14.	1.05
16.	1.044	18.	1.038	20.	1.031	22.	1.025		
48 23.	0.7	-22.	-.926	-20.	-.92	-18.	-.914	-16.	-.908
-14.	-.839	-12.	-.708	-10.	-.576	-8.	-.49	-6.	-.45
-4.	-.36	-2.	-.105	0.	.205	2.	.535	4.	.8
6.	.86	8.	.9	10.	.925	12.	.93	14.	.93
16.	.92	18.	.9	20.	.9	22.	.92		
48 23.	0.8	-22.	-.875	-20.	-.856	-18.	-.838	-16.	-.819
-14.	-.8	-12.	-.79	-10.	-.810	-8.	-.75	-6.	-.69
-4.	-.47	-2.	-.25	0.	.07	2.	.35	4.	.56
6.	.705	8.	.805	10.	.841	12.	.844	14.	.848
16.	.86	18.	.88	20.	.9	22.	.92		
48 23.	0.9	-22.	-.838	-20.	-.810	-18.	-.782	-16.	-.754
-14.	-.716	-12.	-.698	-10.	-.67	-8.	-.666	-6.	-.663
-4.	-.487	-2.	-.31	0.	-.15	2.	.138	4.	.39
6.	.64	8.	.765	10.	.81	12.	.83	14.	.85
16.	.87	18.	.89	20.	.91	22.	.93		
48 23.	1.	-22.	-.822	-20.	-.79	-18.	-.758	-16.	-.726
-14.	-.694	-12.	-.662	-10.	-.63	-8.	-.622	-6.	-.615
-4.	-.428	-2.	-.24	0.	-.05	2.	.2	4.	.449
6.	.7	8.	.806	10.	.85	12.	.865	14.	.88
16.	.895	18.	.91	20.	.925	22.	.94		
9									
96 47.	0.0	-180.	.02	-165.	.2	-155.	.4	-140.	1.0
-120.	1.6	-115.	1.8	-100.	1.95	-90.	2.0	-80.	1.95
-67.	1.8	-43.	1.2	-30.	.6	-22.	.433	-20.	.384
-18.	.334	-16.	.28	-14.	.2358	-12.	.1865	-10.	.1373
-8.	.088	-6.	.042	-4.	.013	-2.	.008	0.	.0085
2.	.009	4.	.01	6.	.0105	8.	.012	10.	.014
12.	.016	14.	.0225	16.	.085	18.	.2054	20.	.276
22.	.347	30.	.6	43.	1.2	67.	1.8	80.	1.95
90.	2.0	100.	1.95	115.	1.8	120.	1.6	140.	1.0
155.	.4	165.	.2	180.	.02				
96 47.	0.3	-180.	.02	-165.	.2	-155.	.4	-140.	1.0
-120.	1.6	-115.	1.8	-100.	1.95	-90.	2.0	-80.	1.95
-67.	1.8	-43.	1.2	-30.	.6	-22.	.433	-20.	.384
-18.	.334	-16.	.28	-14.	.2358	-12.	.1865	-10.	.1373
-8.	.088	-6.	.042	-4.	.013	-2.	.008	0.	.0085
2.	.009	4.	.01	6.	.0105	8.	.012	10.	.014
12.	.016	14.	.0225	16.	.085	18.	.2054	20.	.276
22.	.347	30.	.6	43.	1.2	67.	1.8	80.	1.95
90.	2.0	100.	1.95	115.	1.8	120.	1.6	140.	1.0
155.	.4	165.	.2	180.	.02				
48 23.	0.4	-22.	.436	-20.	.3875	-18.	.339	-16.	.2905
-14.	.242	-12.	.1935	-10.	.145	-8.	.091	-6.	.044
-4.	.013	-2.	.008	0.	.008	2.	.008	4.	.009
6.	.0105	8.	.0125	10.	.0185	12.	.05	14.	.184

16.	.2218	18.	.24	20.	.268	22.	.295		
48 23.	0.5	-22.	.43	-20.	.38	-18.	.33	-16.	.28
-14.	.23	-12.	.193	-10.	.15	-8.	.097	-6.	.051
-4.	.0215	-2.	.01	0.	.008	2.	.008	4.	.009
6.	.013	8.	.035	10.	.071	12.	.128	14.	.2033
16.	.257	18.	.31	20.	.363	22.	.4167		
48 23.	0.6	-22.	.414	-20.	.36	-18.	.322	-16.	.284
-14.	.246	-12.	.1973	-10.	.153	-8.	.102	-6.	.057
-4.	.028	-2.	.01	0.	.008	2.	.008	4.	.015
6.	.042	8.	.083	10.	.132	12.	.189	14.	.238
16.	.287	18.	.336	20.	.385	22.	.434		
48 23.	0.7	-22.	.458	-20.	.415	-18.	.372	-16.	.329
-14.	.286	-12.	.243	-10.	.162	-8.	.117	-6.	.076
-4.	.04	-2.	.011	0.	.009	2.	.014	4.	.053
6.	.092	8.	.136	10.	.1813	12.	.238	14.	.2816
16.	.325	18.	.368	20.	.412	22.	.456		
48 23.	0.8	-22.	.479	-20.	.441	-18.	.403	-16.	.3655
-14.	.3278	-12.	.29	-10.	.225	-8.	.17	-6.	.122
-4.	.075	-2.	.028	0.	.025	2.	.07	4.	.108
6.	.148	8.	.182	10.	.225	12.	.285	14.	.323
16.	.362	18.	.4	20.	.439	22.	.477		
48 23.	0.9	-22.	.5	-20.	.467	-18.	.433	-16.	.4
-14.	.367	-12.	.33	-10.	.262	-8.	.21	-6.	.163
-4.	.115	-2.	.066	0.	.06	2.	.1	4.	.138
6.	.182	8.	.221	10.	.262	12.	.3225	14.	.357
16.	.397	18.	.425	20.	.459	22.	.493		
48 23.	1.0	-22.	.5145	-20.	.4855	-18.	.457	-16.	.428
-14.	.399	-12.	.37	-10.	.297	-8.	.248	-6.	.202
-4.	.152	-2.	.117	0.0	.1	2.	.136	4.	.17
6.	.215	8.	.255	10.	.298	12.	.363	14.	.3925
16.	.422	18.	.452	20.	.4815	22.	.511		
16.	.422	18.	.452	20.	.4815	22.	.511		

F. INPUT CASE LISTING

GRP CASE INPUTS

ITEM NO.	DESCRIPTION	PROGRAM VARIABLE	DIMENSION	REQUIRED
1	Tip Speed	OMEGAR	FPS	YES
2	Radius	R	FT	YES
3	Speed cf Sound	SPSD	FPS	YES
4	Air Density	RHO	SLG/CUFT	YES
5	No. of Blades	XNB	-	YES
6	Forward Speed	VEL	KTS	89, 90
7	Offset Ratio of Flap Hinge (e/R)	ER	-	YES
8-22	Delta X	DX(15)	-	YES
23-37	Local Twist	TW(15)	DEG	92
38-52	Local Mass Density	XMASS(15)	SLG/FT	78,79
53-67	Local Chord	C	FT	YES
68	Delta PSI	DPSI	DEG	**
69	Flap Iteration Limit	FTRL	-	**
70	Initial Beta	BIN	RAD	**
71	Initial Beta *	BPIN	RAD/SEC	**
72	Initial Beta **	BPPIN	RAD/SEC**2	**
73	Lift and Drag Iteration Limit	XITLIM	-	**
74	Required Lift	RL	LB	YES
75	Required Drag	RD	LB	95
76	Lift Tolerance	XLTOL	LB	**
77	Drag Tolerance	XDTOL	LB	**
78	First Moment about Flap Hinge (M)B	FMOM	SLG-FT	38-52
79	Second Moment about	SMOM	SLG-SQFT	38-52
80-82	Shaft Orientation	AG,BGL,CG	DEG	**
83	Pitch-Flap Coupling Angle (Delta 3)	TD3L	DEG	-
84	Drag Increment	DELD	-	-
85	Lat. Cyclic Pitch	A1S	DEG	**

86	Long. Cyclic Pitch	B1S	DEG	**
87	Collective Pitch	T75	DEG	**
88	Inflow Ratio	LAMBDA	-	**
89	Advance Ratio	MUL	-	6, 90
90	VEL Control	UIN	-	6, 89
91	Iteration Output	SKIPIN	-	**
92	Linear Twist	TWIST	DEG	23-37
93	No. of Blade Segments	XNSEG	-	**
94	Climb Rate	RCFPM	FPM	-
95	Flat Plate Area	FPAREA	FT**2	75
96	Thrust Option	TOP	-	-
97	Flapping Re-Use Indicator	PCNV	-	**
100	MU Iteration Tolerance	ABIT	-	-
101	Beta Tolerance	BTOL	-	**
102	Beta* Tolerance	BPTOL	-	**
103	Spar Segments	SPAR	-	-
104-105	Second Harmonic Control Inputs	A2S, B2S	DEG	-
106	Solidity	RSL	-	-
107	Symmetric Airfoil	SYM	-	-
108	Spring Constant	SFH	FT-LB/RAD	-
109	Damping Constant	FDMP	FT-LB/RAD/SEC	-
110	Lift Only Option	ALOPT	-	-
111	Shaft Angle	ALL	DEG	-
112-113	Desired A1 and B1 Flapping	RA1S RB1S	DEG	-
114	A1, B1 Tolerance	TOLAB	DEG	**
115	Tangent Delta 3	TD3B	-	-
116	Phase Angle for Delta 3	PHD3B	DEG	-
117	Induced Velocities	LAML	-	-
118	Induced Velocities	UVL	-	-
119	Not Used			
120	Input Spar Data	BSPL	-	-

121	Azimuthal Printout Indicator	PPSI	DEG	**
122	Minimum Lift Curve Slope	ATEST	-	-
123	Iteration Gain Factor	IGC	-	**
124-125	Not Used			
126	Pre-Coning Angle	PCR	RAD	-
127-137	Not Used			
138	Hub Moment Inplane Aero Forces	INPL	-	-
139-141	Aircraft Yaw, Roll and Pitch Angular Velocities	PSIS, PHIS THFS	RAD/SEC	-
142	CG Station	FSCG	INCHES	-
143	Rotor Center Station	FSMR	INCHES	-
144	CG Waterline	WLCG	INCHES	-
145	Rotor Waterline	WLMR	INCHES	-
146	Aircraft Lateral Velocity	VELY	KTS	-
147	Spar Symmetry	SYMSPR	-	-
156	Airfoil Tables	HIALFA	DEG	**
157	Airfoil Tables	LOALFA	DEG	**
158	Tip Sweep	TIPSWP	DEG	**
159	Sweep Station	TPSWST	-	**
160	Rotor Moments	TRIM	-	-
161-175	Rotor Blade Airfoil Data Assignments	RD	-	**

** Program has automatic default value.

G. GRP INPUT DEFAULT VALUES

ITEM NO	PROGRAM VARIABLE	DEFAULT VALUE
68	DPSI	15.0
69	FTRL	15.0
73	XITLIM	15.0
76	XLTOL	100.
77	XDTOL	50.0
81	BGL	90.0
85	A1S	-1.2 *
86	B1S	7.53 *
87	T75	5.0
88	LAMBDA	-.02
91	SKIPIN	1.0
93	XNSEG	15.0
97	PCNV	1.0
101	BTOL	.001
102	BPTOL	.001
114	TOLAB	0.25
121	PPSI	DPSI
122	ATEST	5.0 **
123	IGC	1.0
156	HIALFA	30.
157	LOALFA	-30.
159	TPSWST	16.
161-175	RB	1.0

* 0. if ABIT, item 100, is non-zero

** -50 is TOP, item 96, is non-zero

H. CASE INPUT DATA

Many of the case inputs are self-explanatcry by their name listing alone, however, many are not. This section will explain the input variables and case options available to the user.

The program enters all the variables into a 200 element array called V(I). Prior to entering case data, the program will automatically do two things. It will initialize the array V(I) to a value of zero. It will assign the default values listed in the previous section to those particular variables.

The V(I) array is associated with the variable names by equivalent statements. The user needs only to enter values for the variables that are different from the default or initialized values. In a multiple case computer run, the user need only enter variables that are different from the preceeding case. If no new value is enter for a variable, the value from the previous case is carried over.

1. Item 6 - Velocity - VEL

The computer program will accept forward velocity in one of two ways. The user will input either VEL, item 6, in knots or advance ratio MUY, item 89. The value of UIN, item 90, determines which variable will be used. If UIN is zero, VEL will be used. If UIN is non-zero, MUL will be used. If VEL is used, the program calculates the advance ratio by the following expression.

$$\mu = \left[(V/\Omega R^2) - \lambda^2 \right]^{1/2}$$

If MUL is used, the program will calculate the flight velocity by the following expression.

$$V = \left[(\mu^2 + \lambda^2) \Omega R^2 \right]^{1/2}$$

2. Item 7 - Hinge Offset - ER

The offset ratio of the flap hinge, E/R, is the distance from the center of the rotor shaft to the vertical flapping hinge, normalized by the rotor radius, item 2.

3. Items 8-22 - Delta X - DX

Delta X is the non-dimensionalized width of each individual blade segment starting with segment number one. There may be up to 15 segments entered. The number of widths entered here must equal the value of Item 93, XNSEG. XNSEG is the number of segments into which the blade is divided. This can range from two to fifteen. It is recommended that a value of ten or more be used for XNSEG. If XNSEG were equal to 12, values of Delta X would be entered for items 8 to 19 and no values would be entered for items 20 to 22. The sum of ER plus the summation of the Delta X's must equal one. ER is the non-dimensional width between the rotor shaft and the flapping hinge offset. Item number 8, which is the first segment width, represents the width between the flapping hinge offset and the point where the actual rotor blade airfoil begins. This area is known as the spar or cut out segment if no spar data were entered. If item 103, SPAR, is zero, the program will assume that this first section creates no lift and has the drag characteristics of the first inputed airfoil data section. Since this area experiences relatively low dynamic pressure, the calculations in this segment do not have an appreciable effect on the outcome of the program. The area between the shaft and the hinge offset, ER, produces neither lift nor drag in the program's calculations. The last segment is

considered a tip loss factor segment. The lift is assumed to be zero, but drag is calculated in the normal manner. In previous runs, the width of this section has been set equal to three percent of the rotor radius, or Delta X equal to .03.

4. Items 23-37 - Twist - TW

The program has two options for entering geometric twist into the calculations. If the blade has linear twist, item 92, TWIST, can be used. If the twist is non-linear, the twist can be entered in items 23-37, TW. If a number is entered for item 92, the program will assume linear twist and ignore all values entered for TW. The local twist at the center of each segment can be entered starting with item 23. If the blade contains ten segments, items 23-32 would be entered and no values for items 33-37 would be entered.

A word of caution is necessary regarding the linear twist option, item 92. The twist is considered to be zero at the 75 percent chord point. The twist is calculated assuming that the twist starts at the rotor shaft and varies linearly out to the rotor tip. If the actual rotor blade airfoil started at the 25 percent radius point with a twist value of -9 degrees, a value of linear twist equal to -12 degrees would have to be entered in order for the correct twist distribution to be calculated by the program.

5. Items 38-52 - XMASS

The program provides two methods for entering the local mass density or the moment of inertia information. The individual mass density for each section can be entered in items 38-52, or the First and Second Moment, FMOM and SMOM, about the Flapping Hinge, can be entered in items 78 and 79. If data are entered for item 79, the Second Moment about the Flapping Hinge, the program will use the information provided by items 78 and 79. If variable 79 is

equal to zero, the program will calculate the First and Second Moments for items 38-52 and ignore any value entered for items 78 and 79.

6. Items 53-57 - Chord

The program has two methods for entering local chord data. The local chord at each segment can be entered starting with segment number one. If the chord is a constant chord, the amount of data to be entered can be reduced to only items 53 and 54. If items 53 and 54 are equal, the program assumes that the chord is constant throughout the radius and will ignore any information entered in items 55-67. Therefore, for constant chord, only enter values for items 53 and 54. If the rotor solidity is not inputed in item 106, the program will compute solidity as follows.

$$\sigma = \frac{b\, c_{.75}}{\pi R}$$

7. Item 68 - DPSI

DPSI, or Delta PSI, is the incremental azimuthal value by which the program advances in its blade flapping and force summation routine. This number must divide evenly into 360 degrees. A minimum value of five degrees is permitted. It has been found that for most cases decresing the value of DPSI below 15 degrees does not improve the accuracy but does increase the computational time. As an example, the rotor horsepower required for one particular run was 1096 RHP for DPSI equal to 15 degrees, 1095 RHP for DPSI equal to 10 degrees and 1097 RHP for DPSI equal to 5 degrees. DPSI has a default value of 15 degrees.

8. Item 69 - FTRL

FTRL is the maximum limit on the number of times that the program will enter the flapping iteration routine in search of a steady state flapping solution. The program has an automatic default value of 15 iterations. The program usually arrives at a steady state flapping solution within three to four iterations. The only method by which the user can actually determine the number of flapping iterations required would be to use one of the debug output options. However, these options will create a huge amount of output and the user is cautioned about their use.

9. Items 70-72 BIN-BPPIN

The program has three options on how to assign the values for the inital flapping angle, velocity, and acceleration at the PSI equal zero position. The user may (1) input the values, (2) have the program itself calculate initial values, or (3) accept the default values of zero. Option three is the most used option. It has been discovered that there is little or no difference in solution time between option two and three. Variable number 97, PCNV, controls which option is to be used. If PCNV is non-zero, the program will use either option one or three. The program initially assigns values of zero to BIN, BPIN, and BPPIN before the initial case data are entered. PCNV is assigned the default value of one. Therefore, with no values entered by the user for items 70-72 and 97, the program will start with an initial value for flapping angle, velocity and acceleration at the PSI equal zero position of zero.

If the user sets PCNV equal to zero, the following formulas are used for determining the inital values. These formulas are derived from page 194 of Ref. 4.

$$\beta = \frac{\gamma}{2}\left[\frac{\theta}{4}(1+\mu^2) + \frac{\lambda}{3}\right] - \frac{\mu\left[\frac{8}{3}\theta - 2\lambda\right]}{1 - \frac{\mu^2}{2}}$$

$$\dot{\beta} = \frac{-\frac{4}{3}\mu\frac{\gamma}{2}\left[\frac{\theta}{4}(1+\mu^2) + \frac{\lambda}{3}\right]}{1 + \frac{\mu^2}{2}}$$

$$\ddot{\beta} = \frac{\mu\left[8/3\,\theta - 2\lambda\right]}{1 - \frac{\mu^2}{2}}$$

The term γ is referred to as the Lock number where

$$\gamma = \frac{C_{.75}\,\rho\, a\, R^4}{I_b}$$

In a run where more than one case is executed at a time, a non-zero value for PCNV allows the previous case values for flapping angle, velocity and acceleration to be used as the initial estimate for these variables in the next case. If PCNV is equal to zero, the inital values will be calculated by the above formulas. Most cases are run by accepting the default value of one for PCNV.

10. Item 73 - XITLIM

After the program calculates a steady state flapping solution for its estimated values of inflow ratio, pitch angle and shaft tilt angle, the program determines the forces and moments generated by this solution. If the forces and, optionally, moments do not meet the required amounts entered by the user, the program will calculate new values to re-enter the flapping routine. XITLIM determines the maximum number of times the program will compare the calculated values to the desired values. The program has a default value of 15 for XITLIM. A majority of the solutions require approximately five iterations to converge. Once the XITLIM limit is exceeded, the program will stop and printout an "Exceeded Limit" statement. The program automatically prints as output the number of Major Iterations it uses in calculating the solution.

The sign of XITLIM controls the Short Iteration Option. If XITLIM is a negative number, the program uses this option. A complete describtion can be found in the section entitled Main Iteration Opticns.

11. Item 74 - Required Lift

The required lift, RL, should equal the actual weight of the helicopter that the rotor system is supporting.

12. Item 75 - Required Drag

The required drag can be entered in one of two ways. It can be entered directly in item 75 or it can be calculated by the program by entering the aircraft's flat plate area in item 95, FPAREA. The drag is equal to the flight path force that the rotor system must overcome to sustain level flight at a certain velocity. Items 75 and 92 can be entered either as positive or negative numbers and the program will provide the correct fcrward flight solution by assigning the proper sign value internally. If a value is entered for FPAREA, the program will ignore any value assigned to RD. The drag for FPAREA is calculated as follows.

$$D = \frac{1}{2} \rho V^2 (FPAREA)$$

If item 92 is not entered, the user must supply the value for the required drag by using the above fcrmula. There are certain options for which the program igncres or does not iterate on drag. An example of this would be when the program is used to estimate wind-tunnel test results. If these options are desired, see variables 96, TOP, and 110, ALOPT.

13. <u>Items 76-77 - Tolerances</u>

XLTOL and XDTOL are the lift and drag tolerances. The program will iterate until both the lift and drag are within the tolerances given by variables 76 and 77. The program has automatic default values of plus and minus 100 pounds for lift and 50 pounds for drag.

14. <u>Items 78-79 - Moments</u>

Information regarding the use of FMOM and SMOM can be located in paragraph five on XMASS.

15. <u>Items 80-82 - Shaft Axis</u>

The gravitational or weight vector must be oriented to the shaft axis of the rotor system. Figure 9 shows the positions of these angles. The shaft can be oriented in any desired direction. The program will automatically assign the proper values for normal helicopter flight. The default values for AG, BGL, and CG are 0, 90, and 0 degrees, respectively. This orients the shaft in the vertical direction for normal flight. If any other orientation is desired, the user must enter the appropiate values for items 80 to 82.

16. <u>Item 83 - Delta 3</u>

Delta three inputs are controlled by variables 83, 115, and 116. These are TD3L, TD3B, and PHD3D, respectively. If the flapping hinge is connected in such a manner as to cause the blade to change pitch due to flapping, this is referred to as a Delta Three hinge. Item 83 is the pitch-flap coupling angle; 115 is the tangent of the Delta Three Bar; and 116 is the phase angle for the Delta Three Bar. The program reduces the pitch angle at a particular azimuth and segment by the quantity TD3 where

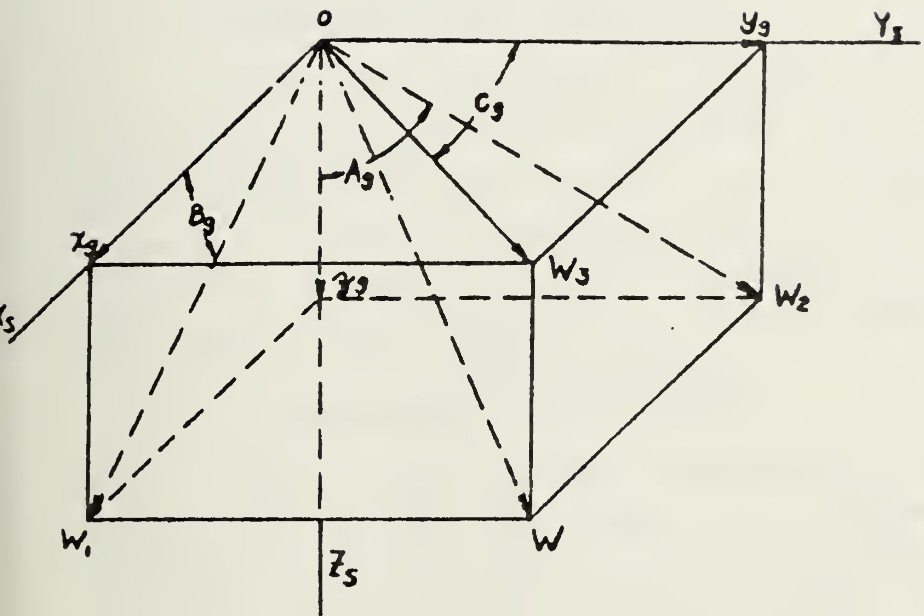


Figure 9 Resolution of Gravitational Force

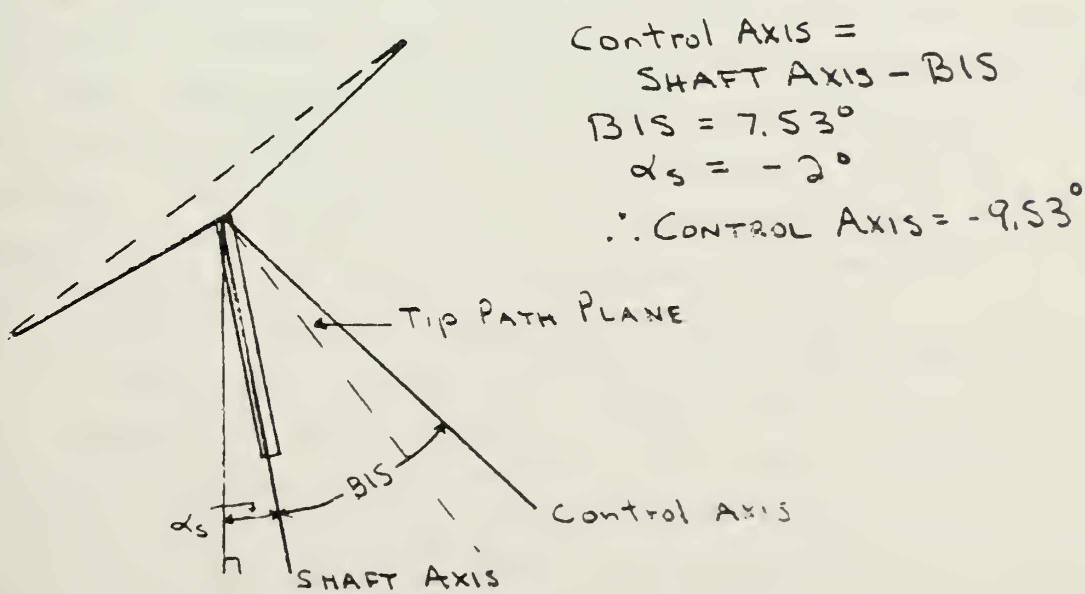


Figure 10 Shaft and Control Axis Diagram

TD3 = TD3L + TD3B*sin(PSI + PHD3D)
Normally, variables 83, 115, and 116 are zero.

17. Item 84 - Drag Increment

The drag increment is a value of delta CD that is added to the value of CD obtained from the airfoil input data decks. This is added as a roughness factor that naturally occurs on blades that are used on production aircraft. A value of .002 is normally used. The value is not added to the drag calculations for spar data.

18. Items 85-86 - Cyclic Pitch

The lateral and longitudinal cyclic pitch is controlled by four variables. The program allows the user to enter both first and second harmonics of cyclic input. The variables A1S and B1S, 85 and 86, control the first harmonic inputs. The variables A2S and B2S, 104 and 105, control the second harmonic inputs. The A's correspond to the lateral inputs and the B's correspond to the longitudinal inputs. The program has automatic default vales for A1S, B1S, A2S and B2S of -1.2, 7.53, 0 and 0 degrees, respectively. The user may enter different values if desired. Unless other options are indicated, the program will keep these cyclic values constant throughout the run and will vary inflow ratio and pitch angle to obtain a final solution. The program will automatically calculate the postion of the shaft axis by the momentum theory and will use the value of B1S to determine the position of the control axis. Figure 10 demostrates this fact.

There is a different option available which allows the program to seek specific values of longitudinal and lateral flapping. This requires the use of variables 100 and 112 - 114. If this option is taken, the values of A1S and B1S are set equal to zero initially and will be changed by the computer in its iteration of the required flapping

angles. The program also has an cption to remove hub rolling and pitching moments. Once a solution is obtained that meets the lift and drag tolerances, the values of A1S and B1S are varied to reduce the moments. This option is controlled by variable 160. Normally, runs are made with the user not inputing values for items 85, 86, 104, 105, 100, 112, 113, 114 and 160.

19. Item 87 - Pitch Angle

Variable 87 is the initial value of the collective pitch at the 75 percent radius station at PSI equal zero azimuthal station. The program has a default value of five degrees. This value is used only to initiate the program. The program, under the normal run option, will vary this value in the process of iterating for a convergent solution. There is an cption where the pitch angle remains fixed as in a wind-tunnel test. This is the TOP option, variable 96.

20. Item 88 - Inflow Ratio

The variable LAMBDA controls the inital estimate of an uniform inflow. Since the equations of the program are done in a gyrocopter mode, inflow is negative when air flows down through the rotor. This is the normal forward flight mode. The program has a default value of -.02 for LAMBDA. The program will iterate on LAMBDA in its normal iteration rountine. The ALOPT, variable 110, option will hold LAMBDA constant.

21. Items 89-90 - MUL

Information regarding the use of MUL and UIN can be found in paragraph one on Flight Velocity.

22. Item 91 - SKIPIN

Information regarding the use of SKIPIN can be fcund in the section of Case Optional Output Indicators.

23. <u>Item 92 - Linear Twist</u>

Information regarding twist can be found in paragraph four on local twist.

24. <u>Item 93 - XNSEG</u>

Information regarding XNSEG can be found in paragraph three on Delta X.

25. <u>Item 94 - Rate of Climb</u>

The program can be made to calculate a complete solution for any given rate of climb or descent. Climb or descent rate must be entered in units of feet per minute, with positive values for climbs and negative values for descents. The program assumes a uniform down or up flow across the entire rotor surface equal to the rate of climb or descent. This value is added as an incremental correction into the calculations of UP and will effect PHI and angle of attack.

26. <u>Item 95 - FPAREA</u>

Information regarding the use of FPAREA, flat plate area, can be found in paragraph twelve on Required Drag.

27. <u>Item 96 - TOP</u>

The TOP option is one of the wind-tunnel options. If TOP is a non-zero number, the program iterates to obtain the required lift of variable 74, but will ignore the required drag of variable 75. Item 87, the collective pitch at the 75 percent radius at PSI equal zero, will be held constant. Item 88, the inflow ratio, will be varied in the major iteration routine. A non-zero value of TOP will result in a value of -50 for item 122, ATEST. ATEST is the minimum accepable value for the lift curve slope when option

96 or 110 is executed. If non-zero values for both TOP and ALOPT are entered, the program will do the TOP option. Shaft angle, item 111, must be inputed by the user.

28. Item 97 - PCNV

Information concerning the use of PCNV, the Flapping Solution Re-Use Indicator, can be found in paragraph nine on Initial Flapping Conditions.

29. Item 98 - PRINT

Information concerning the use of PRINT, the program's main output indicator, can be found in the section entitled Case Optional Output Indicators.

30. Item 99 - XEND

Item 99 is the End of Case signal card. It is the last data variable that will be entered for each case. If XEND is a negative number, the program will stop after it determines a solution for that particular case. However, since an infinite number of cases can be entered for each computer run, XEND also tells the program if there are more cases to go. If XEND is equal to 2.0, the program will assume that the next case will begin by reading in new airfoil data. If XEND is any other positive real number, the program assumes that the next case will use the present airfoil data and will enter only case input data and any of the options which normally follow the case input data. Each time that the variable XEND is entered, be especially careful to follow the format for NNUM for this card. NNUM is the number of inputs per data card. NNUM must be a negative number for this XEND card. It is this negative sign on NNUM which actually keys the computer to stop reading data cards for a particular case.

31. Item 100 - ABIT

Information regarding the use of ABIT can be found in paragraph 40.

32. Items 101-102 - BTOL

In the blade flapping routine, the program searches for a steady state flapping solution for the given conditions of inflow ratio, pitch angle, and cyclic input. The program compares values of flapping angle and velocity at the PSI equal zero azimuthal position on each revolution. If at this position, the difference between the n-th and the (n - 1)th revolution values for flapping angle and velocity is less than BTOL and BPTOL, respectively, the program assumes that it has determined a steady state solution. BTOL and BPTOL have default values of 0.000001 radians and radians per second, respectively. If other values are desired, the user may enter those values for items 101 and 102.

33. Item 103 - SPAR

The number of blade segments using spar data can be inputed in item 103. If no spar data are available, no value for SPAR should be entered. For this case, the program assumes that the first segment is the area between the flapping hinge and the point where the actual airfoil begins on the rotor blade. This area is also referred to as the "cut out" segment. In this case, the program assumes that this cut out area produces zero lift and uses CD information from the first airfoil section for drag calculations. If a non-zero number is entered for SPAR, spar airfoil data must be available. Case input variable 120, BSPL, controls the spar input option. If spar data are to be inputed, BSPL should be assigned a non-zero value. In a multiple case run, where spar data are initially entered,

the variable BSPL is set equal to zero as soon as the spar data are entered. If the program did not do this, the user would have to enter a zero for BSPL for the next case if no new spar data are to be entered. If in a multiple case run, the user decides to enter new spar data, the variable BSPL must be assigned a non-zero value for that particular case.

34. Items 104-105 - A2S B2S

Information regarding the use of the second harmonic control inputs can be found in paragraph 18 on Lateral and Longitudinal Cyclic Inputs.

35. Item 106 - Solidity

Information regarding the use of RSL, rotor solidity, can be found in paragraph six on local chord.

36. Item 107 - SYM

SYM is the non-symmetrical airfoil input control. If the user assigns a non-zero value for SYM, the program will assume that all blade airfoil data are non-symmetrical. The user must enter values for CL and CD for the complete range of angles of attack from -180 to +180 degrees. If the value of SYM is zero, only tabular values from zero to +180 degrees need to be entered. The above holds true also for variable 147, SYMSPR. SYMSPR applies to the spar data exactly in the same manner as SYM applies to the airfoil data.

37. Items 108-109 - SFH FDMP

Values for the spring constant, SFH, and damping constant, FDMP, about the flapping hinge can be entered if known. These variables can be entered to simulate a hingeless rotor system or a system with flapping springs.

38. Item 110 - ALOPT

This is one of the wind-tunnel options. If ALOPT is a non-zero input, the program will iterate to obtain the lift required of variable 74 but will ignore the required drag, variable 75. In this option, variable 87, collective pitch, will be varied, but not variable 88, inflow ratio, in the program calculations. This is the opposite of the TOP, varialbe 96, option.

If a lift curve slope less than ATEST, item 122, is calculated while using this option, the program will stop and produce the following message. "Stall Criterion has been violated -- will go to next case, if any." Item 111, the shaft angle, must be inputed. If non-zero values are entered for both TOP and ALOPT, the program will do the TOP Option.

39. Item 111 - Shaft Angle

Item 111, the shaft angle, must be inputed whenever the TOP or ALOPT options are used.

40. Items 112-114 - RA1S

If variable 100, ABIT, is non-zero, the program will iterate the blade flapping solution in an attempt to obtain the desired lateral and longitudinal flapping angles indicated by variables RA1S and RB1S, respectively. The program will iterate to the accuracy indicated by TOLAB, item 114. Item 112 is RA1S and item 113 is RB1S.

41. Items 115-116 - Delta 3

Items 115 and 116 are the tangent and phase angle of a Delta 3 Bar. Information regarding the use of TD3B and PHD3B can be found in paragraph 16 on the Pitch-Flap Coupling Angle.

42. <u>Items 117-118 - LAML</u>

The program allows the user tc induce a velocity of any form onto the rotor system. This is done in a harmcnic series of the form (A0 + A1*cos(PSI) + B1*sin(PSI) + A2*cos(2*PSI) + B2*sin(2*PSI) + ...) for each segment that the blade is divided into. If variable 117, LAML, is a non-zero number, the program will enter the harmonics of the induced velocities. During the Read routine, LAML, will be assigned a value of zero. Therefore, for each case where different values for the harmonics are desired, LAML will have to be set to a non-zero number. Variable 118, UVL, controls the use of the induced velocities. If UVL, is zero, the induced velocities will all be set equal to zero.

A short example will now be given on the use of the control variables in a multiple case run. Assume that no harmonic induced velocites are desired for the first case. The user would make no inputs for LAML and UVL. For the second case, assume that harmonic induced velocities are desired. LAML and UVL would be set equal to a non-zero number. The harmonic variables would follow the case input data for this particular case. For the third case, it is desired that the same induced velocites be used. The user would not enter any values for LAML and UVL since (1) LAML has been automatically set to zero and hence nc new harmonic data will be entered and (2) UVL is still equal to a non-zero number. It is desired for case four to use no induced velocities. The user now would enter the value of zero for UVL and program will zero out all the induced velocity variables.

This paragraph will describe how to use the variable induced velocity option. The inputs A1, B1, A2, B2, ... are numbers in units of feet per second. If the direction of the velocity is down, a negative sign is assciated with the A's and B's. A negative sign will decrease the angle of

attack for an element originally at a positive angle of attack. It will increase the amount of negative angle of attack for a blade element originally at a negative angle of attack. The values of A's and B's do not effect the uniform inflow ratio, LAMBDA, that the program iterates upon. The format for using the variable inflow velocity is as follows.

1. A value for NHARM is entered in I3 format. NHARM is the maximum degree of the harmonics that is to be used. If the maximum degree used is A3*cos(3*PSI), then NHARM is three.
   The next three paragraphs are repeated for each blade segment.
2. The value for A0 is entered in E15.6 format. The IBM 360-67 at the NPS will accept F15.0 format.
3. The values for A1, A2, A3, ..., up to NHARM are entered on the next data cards in format 5E14.6.
4. The values for B1, B2, B3, ..., up to NHARM are entered on the next data cards in format 5E14.6.
5. Three cards are required for each blade segment whether or not the values are equal to zero. If the user has 15 blade segments, a minimum of 45 data cards are required.

43. Item 120 - BSPL

Information concerning the use of BSPL can be found in paragraph 33 entitled Number of Spar Airfoil Data Segments.

44. Item 121 - PPSI

PPSI represents a delta PSI for printout purposes. PPSI has a default value equal to DPSI, variable 68. PPSI shall never be a smaller increment than the incremental DPSI used to calculate the solution.

45. Item 122 - ATEST

ATEST is the minimum acceptable value of the lift curve slope when option TOP or ALOPT is used. If no value is assigned, ATEST has a default value of 5 (1/rad). When the TOP option is used it has a automatic value of -50 (1/rad). The lift curve refers to the increase in rotor lift with the tilting back of the tip path plane. A check on it for a minimum is for convergence purpose only.

46. Item 123 - IGC

IGC is the Iteration Gain Control factor. If the major iteration fails to converge, choosing a fractional value for IGC can greatly speed convergence. This may be especially helpful when parts of the rotor are in stall. The amounts by which the convergence algorithm changes the independent variables is multiplied by IGC. Setting item 91, SKIPIN, equal to zero may help the user decide if this IGC option might be useful.

47. Item 126 - PCR

The pre-coning angle in radians may be entered here.

48. Item 138 - INPL

Input 1.0 for INPL in order to remove hub moment inplane aerodynamic forces from the calculation of aerodynamic pitch and roll moments about the shaft axis.

49. Items 139-141 - PSIS

Variables PSIS, PHIS and THFS represent aircraft angular velocites. The aircraft can be given any angular velocity in yaw (PSIS), pitch (PHIS), and roll (THFS) in radians per second by the use of these variables. They effect the calculations of UP, UT and UR. Paragraph 50 contains additional information.

50. Items 142-145 - CG

If the angular velocities, items 139 - 141 are entered, they are used in the calculations of UP, UT and UR. If no values for items 142 - 145 are entered, the program assumes that the rotor system rotates due to the angular velocities about the center of the shaft. If values are entered for items 142 - 145, the calculations will assume that the entire rotor shaft is rotating about the center of gravity. Variables 142 - 145 are FSCG, FSMR, WLCG and WLMR. FSCG is the longitudinal CG position while FSMR is the longitudinal position of the main rotor. WLCG is the CG waterline station while WLMR is the main rotor's waterline, or vertical position. All of these values must be entered in units of inches.

51. Item 146 - VELY

The aircraft's lateral speed in knots can be entered here.

52. Item 147 - SYMSPR

If the spar data are symmetrical, do not enter a value for SYMSPR. The program will only use values for CL and CD between zero to +180 degrees. If the spar data are non-symmetrical, enter any non-zero value for SYMSPR. The program will require values from -180 to +180 degrees.

53. Items 156-157 - HIALFA

In order for the program to properly calculate the region in and around the reverse flow region, the values of CL and CD are required to be known at high and low angles of attacks approaching 180 degrees. However, in order to save the user from having to enter a whole range of angles of attack for all Mach numbers, the program has an option where for angles above HIALFA, 156, and below LOALFA, 157, the Mach number is set equal to zero for table lookup purposes. The user is only required to enter large angles for the first two Mach number tables. HIALFA and LOALFA have default values of +30 and -30 degress, respectively.

54. Items 158-159 - Tip Sweep

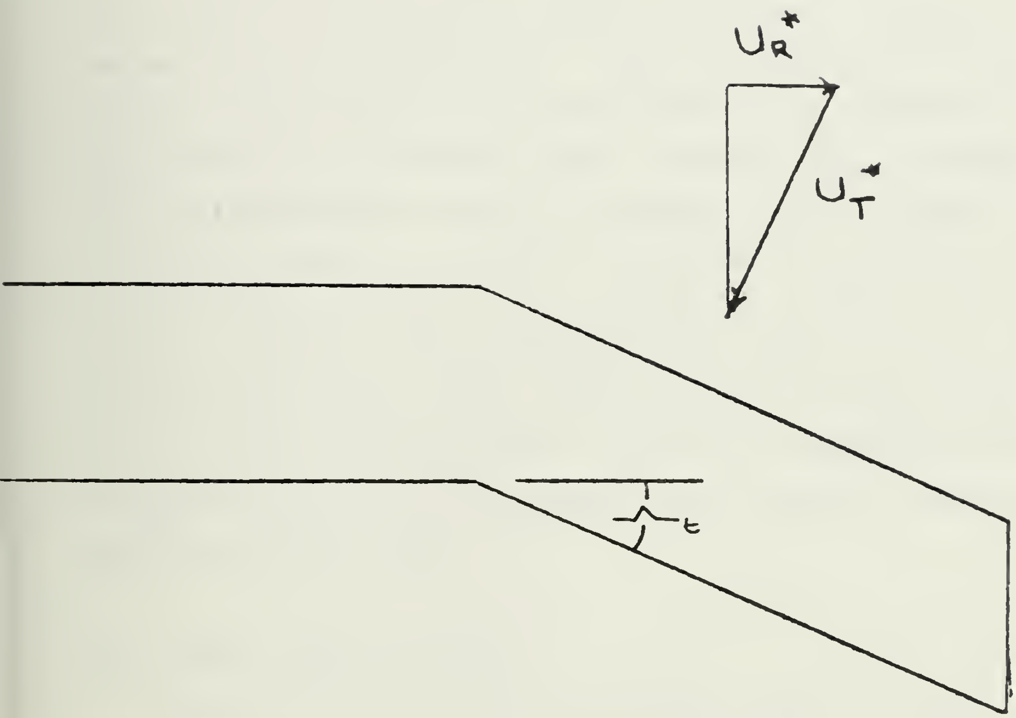
The GRP program will properly calculate the airflow sweep angle, UT, UR, and pitch angle of a swept tip airfoil. TIPSWP is the amount of sweep of the tip measured in degrees. TPSWST is the blade segment number at which the sweep begins. The program assumes that the remaining outboard segments starting with TPSWST are swept the number of degrees indicated by TIPSWP. UT and UR are modified for these segments as shown is Figure 11.

55. Item 160 - TRIM

If TRIM is a non-zero value, the program will attempt to adjust A1S and B1S in order to reduce the rolling and pitching moments to less than plus or minus 100 pounds. It will first obtain a solution which will satisfy the required lift and drag, then it will adjust A1S and B1S to reduce the moments.

56. Items 161-175 - RB

Variables 161 - 175 assign the proper airfoil data to blade segments one through fifteen. The program will



$$UR = UR\cos\Lambda_t + UT\sin\Lambda_t$$

$$UT = UT\cos\Lambda_t - UR\sin\Lambda_t$$

Figure 11 Tip Sweep Calculation Diagram

accept up to five airfoil data decks. The RB array is initialized with the value of one for all 15 segments. If only one blade airfoil deck is used, there is no need to enter any values for RB. Only enter values for the segments which will use airfoil data sets two through five. If no spar data are entered, SPAR equals zero, segment number one is considered the cut out segment and is assigned the value of RB(1) equals one for calculation purposes and the value of RB(1) equals zero for printout indentification. In this case, segment one produces only drag but no lift. If SPAR is greater than zero, RB(I), I = 1, SPAR, will be assigned the value of zero for printout indentification. These segments will use the spar data entered and will calculate both lift and drag.

I. CASE INPUT FORMAT

Below is located the format that is used to input case data to the program. All input data cards are of the format (I2, I4, 5F12.0). The input cards contain seven fields which are called NNUM, NLOC, C(1), C(2), C(3), C(4) and C(5). An example of a data input card is as follow.

```
    5   1   700.     26.8     1148.6     .002246     4.0
```

1. NNUM is the number of inputs on this card, where C(N) are the inputs. NNUM must appear in either column one or two. NNUM has a minimum of one and a maximum of five. In the above example NNUM is five.
2. NLOC is the item or variable number of input C(1). This refers to the item numbers that are found in the section on Case Input Listings. NLOC is in I4 format and must be right justified in columns four through six. In the example NLOC refers to item number one, the Rotor Tip Speed.

3. C(1) through C(5) are the values corresponding to the input items NLOC through NLOC + NNUM. Each value must contain a decimal point and be in columns 7 - 18 for C(1), 19 - 30 for C(2), 31 - 42 for C(3), 43 - 54 for C(4) and 55 - 66 for C(5). In this example, values are entered for variables one through five, the Tip Speed, Radius, Speed of Sound, Air Density and Number of Blades.
4. Omision of NNUM will cause program termination with an error explanation statement. NNUM greater than five will cause unknown problems. Omission of NLOC will cause the present card's values of C(N) to be entered into the items indicated by the previous card's NLOC. Failure to right justify NLOC, or NLOC greater than 200, will cause unknown problems. Failure to properly locate correctly any input value within its own field on the card will cause errors in both that input and the number whose field it encroaches on.

J. CASE OPTIONAL OUTPUT INDICATORS

The program has two variables that control the output printout, variable 91, SKIPIN, and 98, PRINT. The program will automatically produce a printout of the case input data for each case and a one-page summary of the inital conditions and iteration limitations the user placed upon the program. It will also produce a one-page summary of the resulting forces, moments and calculated rotor horsepower for the final converged solution. The user can also receive an echo printout of the airfoil and spar data decks. If this echo printout is desired, the user will find the correct printout indicators described in sections C and D

entitled Blade and Spar Data Deck Requirements.

The main optional printout variable is variable 98, PRINT. PRINT can be a number from 1 to 1,111,111 depending upon the option desired. If no value is enter for PRINT, the user will receive the printout described above. Below, is listed the PRINT Options. If, for example, PRINT is assigned a value of 111, the user will receive printout options 1, 10 and 100.

OPTIONAL OUTPUT INDICATORS

Option 1	Angle of attack, Mach number, section lift and drag coefficients, inflow angle, lift, and sweep angle at each azimuthal position for each radial blade segment. Only for converged flapping solution.
Option 10	Converged flapping angle, rate, and acceleration at each azimuthal position.
Option 100	Converged integrated forces on blade at each azimuthal station.
Option 1000	Harmonic analysis of blade forces for converged case.
Option 10000	Harmonic analysis of air loads for converged case.

DEBUGGING OR TRANSIENT OPTIONS

Option 100000	Transient flapping angle, rate, and acceleration at each azimuthal station.
Option 1000000	Option 100000 plus blade velocities, angles, Mach number, section coefficients, and lift for each blade segment at each azimuthal station.

The user is cautioned that the debugging options can give a huge amount of output data.

The second printout option is the variable SKIPIN, number 91. This variable controls the summary force, moment and horsepower output discussed in the first paragraph. If SKIPIN is greater than zero, this summary will be printed only for the final converged solution. If SKIPIN is equal to zero or a negative number, this summary will be printed for each loop through the major iteration (force summation) routine. SKIPIN has a default value of one. If the program is not converging to a solution, the user can see immediately, with very little extra printout, exactly what intermediate solutions the program is producing by setting SKIPIN equal to zero. This may help the user in deciding whether or not to use the Iteration Gain Factor, IGC, variable 123.

K. IBM 360 EXECUTION CONTROL CARDS

This section illustrates the control cards required to execute the GRP program using the IBM 360 at the Naval Postgraduate School. The program may be run under OS or CP/CMS. There are two ways of running the program under OS. The first is to run the entire program and data through the computer at the same time. The second way is to store the main program on a disk as a library program and enter only the data through the card reader for each desired case. The second method has the two advantages of (1) not requiring the user to enter the entire 1100 card main program through the card reader for each run and (2) the amount of CPU time required can be reduced since the main program does not have to be recompiled for each run. The program requires approximately one minute and forty seconds of CPU time to compile. The normal run time for each case is approximately

20 CPU seconds. This can vary with the amount of printout data requested. If the program is compiled on the CP/CMS, the user will have to request 344K bytes core size on the login message. The standard 256K bytes core size is not large enough for compiling. However, once the program has been compiled, it can be executed within the 256K normally available.

The following cards are required to execute the entire program through the card reader at one time.

```
Standard Job Card
// EXEC FORTCLG,REGION.FORT=150K
// REGION.GO=180K
//FORT.SYSIN DD *
Main GRP Program
/*
//GO.SYSIN DD *
Case Input Data
/*
```

The following two programs are used to reserve space and load the program onto a disk.

```
Standard Job Card
// EXEC PGM=IEFBR14
//LOAD DD DSN=S1395.HELO,UNIT=3330,VOL=SER=DISK01
// DISP=(NEW,KEEP),LABEL=RETPD=150,SPACE=(CYL,(1,1,1))
/*
Standard Job Card
// EXEC FORTCL,REGION.FORT=180K
//FORT.SYSIN DD *
Main GRP Program
/*
// LINK.SYSLMOD DD UNIT=3330,VOL=SER=DISK01,
// DSN=S1395.HELO(GRP),DISP=SHR
```

The S1395 used above and below must be change to S for student or F for faculty with the appropiate user number instead of 1395. The following cards must be used to

execute the program once stored on a disk.

Standard Job Card

```
//GO EXEC PGM=GRP,REGION=180K
//STEPLIB DD UNIT=3330,VOL=SER=DISK01,DISP=SHR,
// DSN=S1395.HELO
//FT06F001 DD SYSOUT=A,DCB=(RECFM=FBA,LRECL=133,BLKSIZE=3325
//FT05F001 DD *
Case Input Data
/*
```

J. Sample Program Output

This section describes in detail the output available from the GRP program. In addition, a sample computer output is included with each describtion. The program will print up to ten different tables. Seven of these tables are optional and are not automatically printed. The ten tables are as follows.

1. Echo Printout of Rotor Blade and Spar Data
2. Case Input Data Card Listings
3. Summary of Input Data
4. Debugging or Transient Information (Options 100,000 and 1,000,000)
5. Summary of Forces, Moments and Horsepower
6. Converged Flapping Sclution (Option 10)
7. Converged Integrated Forces (Option 100)
8. Harmonic Analysis of Z Force (Option 1000)
9. Converged Blade Analysis (opticn 1)
10. Harmonic Analysis of Air Loads (Option 10,000)

The input variable PRINT, item 98, controls the output of items four and six through ten. Items two, three and five are always outputed. Item one is controlled by the first data card on the rotor blade and spar section input decks.

1. Echo Rotor Blade Printout

The next page contains a partial sample Echo Printout of Rotor Blade Input Data. This printout illustrates that (1) the printout was requested (WBLADE = 10.), (2) there are two airfoil decks to be entered, (3) there are nine Mach numbers for which CL's are to be read in and (4) the remaining portion of the printout is the values of Mach numbers, angles of attack and lift coefficients for the first airfoil deck.

58	48.000	0.0	-180.000	0.0	-172.000	0.800	-166.000	0.800	-160.000	0.660
	-158.000	0.680	-148.000	1.000	-142.000	1.080	-130.000	1.000	-60.000	-1.000
	-50.000	-1.090	-40.000	-1.090	-30.000	-1.010	-22.000	-0.980	-20.000	-0.975
	-18.000	-0.969	-16.000	-0.963	-14.000	-1.070	-12.000	-0.718	-10.000	-0.366
	-8.000	-0.245	-6.000	-0.390	-4.000	-0.400	-2.000	-0.185	0.0	0.029
	2.000	0.244	4.000	0.459	6.000	0.673	8.000	0.883	10.000	1.103
	12.000	1.250	14.000	1.100	16.000	0.950	18.000	0.982	20.000	0.984
	22.000	0.987	30.000	1.010	40.000	1.090	50.000	1.090	60.000	1.000
	132.000	-1.000	140.000	-1.060	142.000	-1.060	148.000	-1.000	158.000	-0.680
	160.000	-0.660	166.000	-0.800	172.000	-0.800	180.000	0.0		
58	48.000	0.300	-180.000	0.0	-172.000	0.800	-166.000	0.800	-160.000	0.660
	-158.000	0.680	-148.000	1.000	-142.000	1.080	-130.000	1.000	-60.000	-1.000
	-50.000	-1.090	-40.000	-1.090	-30.000	-1.010	-22.000	-0.980	-20.000	-0.975
	-18.000	-0.969	-16.000	-0.963	-14.000	-1.070	-12.000	-0.718	-10.000	-0.366
	-8.000	-0.245	-6.000	-0.390	-4.000	-0.400	-2.000	-0.185	0.0	0.029
	2.000	0.244	4.000	0.459	6.000	0.673	8.000	0.883	10.000	1.103
	12.000	1.250	14.000	1.100	16.000	0.950	18.000	0.982	20.000	0.984
	22.000	0.987	30.000	1.010	40.000	1.090	50.000	1.090	60.000	1.000
	132.000	-1.000	140.000	-1.060	142.000	-1.060	148.000	-1.000	158.000	-0.680
	160.000	-0.660	166.000	-0.800	172.000	-0.800	180.000	0.0		
48	23.000	0.400	-22.000	-0.960	-20.000	-0.960	-18.000	-0.962	-16.000	-0.966
	-14.000	-0.824	-12.000	-0.532	-10.000	-0.240	-8.000	-0.300	-6.000	-0.440
	-4.000	-0.420	-2.000	-0.185	0.0	0.048	2.000	0.282	4.000	0.519
	6.000	0.749	8.000	0.983	10.000	1.170	12.000	1.130	14.000	1.030
	16.000	0.980	18.000	0.986	20.000	0.972	22.000	0.979		
48	23.000	0.900	-22.000	-0.914	-20.000	-0.910	-18.000	-0.906	-16.000	-0.902
	-14.000	-0.803	-12.000	-0.528	-10.000	-0.400	-8.000	-0.330	-6.000	-0.220
	-4.000	-0.440	-2.000	-0.196	0.0	0.048	2.000	0.292	4.000	0.536
	6.000	0.780	8.000	0.960	10.000	1.010	12.000	0.960	14.000	1.070
	16.000	1.060	18.000	1.070	20.000	1.065	22.000	1.060		
48	23.000	0.600	-22.000	-0.934	-20.000	-0.930	-18.000	-0.926	-16.000	-0.922
	14.000	-0.805	-12.000	-0.660	-10.000	-0.610	-8.000	-0.550	-6.000	-0.520
	-4.000	-0.470	-2.000	-0.199	0.0	0.072	2.000	0.343	4.000	0.614
	6.000	0.840	8.000	0.910	10.000	0.946	12.000	1.000	14.000	1.053
	16.000	1.075	18.000	1.064	20.000	1.053	22.000	1.042		
48	23.000	0.700	-22.000	-0.926	-20.000	-0.920	-18.000	-0.914	-16.000	-0.908
	-14.000	-0.680	-12.000	-0.830	-10.000	-0.780	-8.000	-0.740	-6.000	-0.680
	-4.000	-0.580	-2.000	-0.255	0.0	0.070	2.000	0.395	4.000	0.720
	6.000	0.830	8.000	0.882	10.000	0.920	12.000	0.924	14.000	0.928
	16.000	0.920	18.000	0.900	20.000	0.900	22.000	0.920		
48	23.000	0.800	-22.000	-0.875	-20.000	-0.856	-18.000	-0.838	-16.000	-0.819
	-14.000	-0.800	-12.000	-0.790	-10.000	-0.810	-8.000	-0.750	-6.000	-0.690
	-4.000	-0.470	-2.000	-0.250	0.0	0.070	2.000	0.350	4.000	0.560
	6.000	0.705	8.000	0.805	10.000	0.842	12.000	0.845	14.000	0.848
	16.000	0.860	18.000	0.880	20.000	0.900	22.000	0.920		
48	23.000	0.900	-22.000	-0.838	-20.000	-0.810	-18.000	-0.782	-16.000	-0.754
	-14.000	-0.726	-12.000	-0.698	-10.000	-0.670	-8.000	-0.666	-6.000	-0.663
	-4.000	-0.486	-2.000	-0.310	0.0	-0.150	2.000	0.138	4.000	0.390
	6.000	0.640	8.000	0.785	10.000	0.810	12.000	0.829	14.000	0.848
	16.000	0.887	18.000	0.886	20.000	0.905	22.000	0.924		
48	23.000	1.000	-22.000	-0.822	-20.000	-0.790	-18.000	-0.758	-16.000	-0.726
	-14.000	-0.694	-12.000	-0.662	-10.000	-0.630	-8.000	-0.622	-6.000	-0.615
	-4.000	-0.428	-2.000	-0.240	0.0	-0.050	2.000	0.200	4.000	0.449
	6.000	0.700	8.000	0.806	10.000	0.850	12.000	0.865	14.000	0.880
	16.000	0.895	18.000	0.910	20.000	0.925	22.000	0.940		

2. Input Data Card Listing

The next page contains a sample Case Input Data Card Listing. This is one of the automatic printouts. It is an echo printout of the input data cards

INPUT CARD LISTING

5	1	724.5998535156	26.8259865723	1148.6298828125	0.0022459999	4.0000000000
1	6	60.0000000000				
5	7	0.0465999991	0.0573999500	0.0573999954	0.0985999703	0.0999999642
5	12	0.0599999642	0.0610999987	0.0599999987	0.0599999987	0.0599999987
5	17	0.0599999987	0.0599999987	0.0625000000	0.0346999986	0.0116999969
1	22	0.0299999975				
5	23	9.7799997330	9.7799997330	9.0000000000	7.2199993134	5.3299995237
5	28	3.8899993896	2.6699991226	1.6299999237	0.2199999690	-0.3299999633
5	33	-0.6699999571	-3.3299999237	-3.5599994659	-3.3299999237	-2.7799997330
5	53	1.0000000000	1.2409992218	1.7129993439	1.7129993439	1.7129993439
5	58	1.7409992218	1.7409992218	1.7409992218	1.7409992218	1.6699998856
5	63	1.6699998856	1.7229995728	1.7229995728	1.7229995728	1.7229995728
1	74	20829.0000000000				
2	76	25.0000000000	10.0000000000			
2	78	85.0000000000	1450.0000000000			
1	84	0.0019999999				
1	93	15.0000000000				
1	95	35.7999877930				
1	98	111.0000000000				
1	107	1.0000000000				
2	156	22.0000000000	-22.0000000000			
2	158	20.0000000000	13.0000000000			
2	166	2.0000000000	2.0000000000			
4	168	2.0000000000	2.0000000000	2.0000000000	2.0000000000	
-1	99	-1.0000000000				

3. Summary of Input Data

The next page contains the automatic Summary of Input Data printout. The following information can be seen on this sample output.

a. The blade was divided into 15 segments starting from the hinge offset and proceeding outward.

b. No values were entered for the local mass desnsity, input variables 38 - 52. Instead, values for the First Moment, M(M) = 85, and the Second Moment, MOM - INERTIA = 1450, about the Flapping Hinge, input items 78 and 79, were entered.

c. The X row indicates the calculated centers of each segment expressed in a percentage of the distance out the rotor blade.

d. The BLADE DECK row indicates that the first blade segment was considered a Spar segment. Segments two through five and twelve through fifteen belong to airfoil data deck number one, while segments six through eleven belong to airfoil data deck number two.

e. The rest of the information, with one exception, is a summary of the case input data. The exception is the term THRUST FACTOR. This is the value used to nondimensionalize all the calculated forces in the program. The THRUST FACTOR equals $\rho \pi R^2 (\Omega R)^2$. Moments are nondimensionalized by the THRUST FACTOR times the radius.

f. The program checks to see if all the blade segments, delta X's, plus the distance from the shaft to the hinge offset, E/R, add up to one. If, on the printout, SUM(DX) + E/R does not equal one, the user has made a mistake somewhere with the delta X's or in the E/R number.

NAVAL AIR SYSTEMS COMMAND   AIRFRAME DIVISION   AERO + HYDRO BRANCH   PERFORMANCE SECTION   ROTARY WING UNIT
UNITED STATES NAVY   DEPARTMENT OF DEFENSE(?)

INPUT QUANTITIES

STATION	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
MASS SLUG/FT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
DELTA X	0.0974	0.0974	0.0986	0.1000	0.1000	0.0611	0.0600	0.0600	0.0600	0.0600	0.0600	0.0625	0.0347	0.0117	0.0300
X	0.0953	0.1727	0.2507	0.3500	0.4500	0.5305	0.5911	0.6511	0.7111	0.7711	0.8311	0.8923	0.9409	0.9641	0.9850
CHORD FEET	1.0000	1.2410	1.7130	1.7130	1.7130	1.7410	1.7410	1.7410	1.7410	1.6700	1.6700	1.7230	1.7230	1.7230	1.7230
TWIST DEG.	9.7800	9.7800	9.0000	7.2200	5.3300	3.8900	2.6700	1.8300	0.2200	-0.3300	-0.6700	-3.3300	-3.5600	-3.3300	-2.7800
BLADE DECK	0.	1.	1.	1.	1.	2.	2.	2.	2.	2.	2.	1.	1.	1.	1.

CASE NO. 1

OMEGA-R =	724.60	FT/SEC	AG =	0.0	DEGREES
RADIUS =	26.83	FEET	BG =	90.00	DEGREES
SPEED OF SOUND =	1148.63	FEET/SEC	CG =	0.0	DEGREES
RHO =	0.0022460	SLUGS/CUBIC FT.	TAN DELTA 3 =	0.0	
G =	32.20	FEET/SEC SQ.	E/R =	0.0466	
NO. BLADES (B) =	4		DELTA DRAG =	0.0020	
TIP MACH NO. =	0.6308		MOM-INERTIA =	1450.0000000	SLUG FEET SQ.
SIGMA =	0.0887		SUM(DX)+E/R =	1.0000	
M(M) =	85.0000000	SLUG FEET	VELOCITY =	60.00	KNOTS
THRUST FACTOR =	2666839.		DELTA PSI =	15	DEGREES
FLAP DAMPER =	0.	FT. LB./RADIAN/SEC.	HINGE SPRING=	0.	FT. LB./RADIAN
IT. GAIN CON. =	1.00		PRE-CONING =	0.0	DEGREES
TAN D3 BAR =	0.0		D3 BAR PHASE =	0.0	DEGREES
FS(CG) =	0.0	INCHES	V(Y)S =	0.0	KNOTS
FS(MR) =	0.0	INCHES	PSI * =	0.0	RADIANS/SEC
WL(CG) =	0.0	INCHES	PHI * =	0.0	RADIANS/SEC
WL(MR) =	0.0	INCHES	THETA(F) * =	0.0	RADIANS/SEC

TOLERANCE ON BETA = 0.00100   TOLERANCE ON BETA* = 0.00100   FLAPPING ITERATION LIMIT = 15

REQUIRED LIFT = 20829.00   REQUIRED DRAG = -412.88   MAJOR ITERATION LIMIT = 15

LIFT TOLERANCE= 25.00   DRAG TOLERANCE= 10.00

4. <u>Debugging or Transient Information</u>

The next page illustrates the Debugging or Transient Printout. This is PRINT Option 1,000,000. The information available includes flapping angles, rates and accelerations at each azimuthal position with a radial position display of UP, UT, U, PHI, Angle-of-Attack, Mach Number, CL, CD and Lift Per Inch produced.

This option is generally outputed only when the user is experiencing unknown difficulties with the GRP program. The program will output all of the above information for every revolution and iteration until a converged solution is obtained or the program runs out of allowable computer time. If desired, the variable SKIPIN, item 91, will provide a printout of the Forces, Moments and Horsepower Summary after each major iteration.

PSI = 15 DEGREES REV 1 BETA = 0.00000129 BETA* = 0.00000122 BETA** = 0.07691574

UP	UT	U	PHI	ALPHA	MACH NO.	CL	CD	LOAD(LB/IN)/
-0.0200004	0.2497559	0.3749867	-3.0574017	2.8446865	0.2352067	0.0	0.0	0.0
-0.0200006	0.3997558	0.4878953	-2.3494234	3.9032383	0.3060275	0.4142136	0.0085000	8.2283955
-0.0200008	0.5497558	0.6168213	-1.8581762	3.8629398	0.3868950	0.4161850	0.0085000	14.3783274
-0.0200010	0.6747558	0.7304330	-1.5690880	3.4327545	0.4581569	0.3847123	0.0090816	19.3185425
-0.0200011	0.7747557	0.8237011	-1.3913908	2.9472160	0.5166594	0.3413848	0.0095000	22.1963854
-0.0200012	0.8747557	0.9183869	-1.2479219	2.3826094	0.5760491	0.2830600	0.0095000	23.1671753
-0.0200013	0.9497556	0.9900873	-1.1575413	1.9227781	0.6210224	0.2383178	0.0083604	22.3795319
-0.0200014	0.9997556	1.0381460	-1.1039524	1.6029921	0.6511668	0.2087631	0.0079535	22.0744781
-0.0200014	1.0347548	1.0718927	-1.0691948	1.3738913	0.6723341	0.1847415	0.0085567	20.8727417
-0.0200014	1.0597553	1.0960464	-1.0456314	1.2078753	0.6874843	0.0	0.0094483	-0.0211184

PSI = 30 DEGREES REV 1 BETA = 0.00262245 BETA* = 0.01990843 BETA** = -0.01094304

UP	UT	U	PHI	ALPHA	MACH NO.	CL	CD	LOAD(LB/IN)/
-0.0221490	0.3194170	0.4063405	-3.1246576	2.2969646	0.2548730	0.0	0.0	0.0
-0.0251353	0.4694165	0.5325208	-2.7053966	2.3056164	0.3340184	0.2459640	0.0085000	6.2571630
-0.0281216	0.6194159	0.6686267	-2.4104948	1.7392778	0.4193895	0.1902028	0.0086939	8.0148640
-0.0306101	0.7444155	0.7859301	-2.2320976	1.0615234	0.4929668	0.1215528	0.0094297	7.2275648
-0.0326010	0.8444151	0.8813027	-2.1199560	0.4442472	0.5527884	0.0522613	0.0095000	3.0374790
-0.0345918	0.9444147	0.9776045	-2.0277910	-0.2160130	0.6131927	-0.0264918	0.0095427	-2.5266533
-0.0360849	1.0194139	1.0502863	-1.9689112	-0.7313929	0.6587816	-0.0963657	0.0101449	-10.5587292
-0.0370803	1.0694141	1.0989151	-1.9336796	-1.0824280	0.6892836	-0.1492200	0.0102873	-17.9221191
-0.0377771	1.1044140	1.1320271	-1.9106960	-1.3311462	0.7106800	-0.1947136	0.0111277	-24.8904114
-0.0382749	1.1294136	1.1574259	-1.8950567	-1.5101538	0.7259839	0.0	0.0145737	-0.0658250

PSI = 45 DEGREES REV 1 BETA = 0.00740225 BETA* = 0.01639780 BETA** = -0.08475673

UP	UT	U	PHI	ALPHA	MACH NO.	CL	CD	LOAD(LB/IN)/
-0.0227411	0.3792349	0.4314013	-3.0217161	1.4916553	0.2705922	0.0	0.0	0.0
-0.0252008	0.5292307	0.5678830	-2.5434294	1.1178379	0.3561990	0.1197473	0.0085000	3.6569128
-0.0276604	0.6792266	0.7098483	-2.2331905	0.3754587	0.4452453	0.0417392	0.0089524	2.0339022
-0.0297101	0.8042231	0.8303182	-2.0505733	-0.3796406	0.5208089	-0.0440540	0.0095000	-3.0232067
-0.0313499	0.9042203	0.9275603	-1.9368658	-1.0355316	0.5818030	-0.1233279	0.0095000	-10.0742922
-0.0329897	1.0042171	1.0253344	-1.8437862	-1.7222605	0.6431308	-0.2215279	0.0078106	-23.2830352
-0.0342195	1.0792150	1.0989285	-1.7844200	-2.2520905	0.6892920	-0.3104696	0.0078566	-37.5716553
-0.0350394	1.1292133	1.1480942	-1.7489185	-2.6108971	0.7201307	-0.3836758	0.0222078	-51.4666595
-0.0356134	1.1642122	1.1825514	-1.7257614	-2.8643351	0.7417436	-0.4490120	0.0362347	-63.1824493
-0.0360233	1.1892119	1.2071829	-1.7100039	-3.0463991	0.7571935	0.0	0.0468242	-0.2076074

5. Forces Summary

The next printout illustrates the Summary of Forces, Moments and Horsepower. This page is automatically outputed for the converged solution. A printout of this summary can be obtained for each loop through the major iteration routine by the use of the input variable SKIPIN, item 91. The following information can be observed from this sample printout.

a. The cyclic lateral and longitudinal inputs, A1S, B1S, A2S and B2S are printed at the tcp of the page. This example indicates that there were no second harmonic inputs for A2S and B2S, which is normal.

b. THETA .75 is the pitch angle of the blade at the 75 percent radius station at the PSI equals zero azimuthal position. In most options the program will iterate upon the values for THETA .75 in its search for a converged solution.

c. LAMBDA refers to the converged value for the uniform inflow ratio. If a rate of climb or descent was used in the case, that rate divided by the tip speed would have to be subtracted from or added to this value of LAMBDA, respectively.

d. MU(X)S and MU(Y)S are the advance ratios in the longitudinal and lateral directions with respect to the shaft axis.

e. CT, CQ, CH, CL and CD are the calculated overall coefficients of Thrust, Torque, H Force, Lift and Drag. All of these items are nondimensionalized by the value of the Thrust Factor.

f. Lift and Drag forces are calculated with respect to the relative wind axis. Thrust and H forces are calculated with respect to the control axis. Z forces are calcuated with respect to the shaft axis. X and Y forces are calculated perpendicular to the shaft axis.

g. The Equivalent Drag is the total drag force created by the fuselage, flat plate area times dynamic

pressure, plus the profile drag created by the turning rotor system.

h. The Equivalent P. A., or Equivalent Flat Plate area is obtained by dividing the Equivalent Drag by the dynamic pressure.

i. Alpha(S) is the shaft axis orientation while Alpha(c) is the control axis orientation. The program uses momentum theory to calculate Alpha(S). Alpha(C) is determined from the following relationship, Alpha(S) = Alpha(C) + B1S.

j. LAT. DIS. and LONG. DIS. are the lift vector offset as a percentage of the rotor radius from the rotor shaft to create the program's rolling and pitching moments.

K. PM and RM are the calculated aerodynamic pitch and roll moments about the shaft axis. The SHEARS Hub Pitch and Roll Moments are calculated from summing the aerodynamic, inertia and elastic hub restraint moments.

```
  A1S         B1S         A2S         B2S         THETA .75-       LAMBDA(S)       ML(X)S       ML(Y)S
 -1.20        7.53        0.0         0.0           6.98           -0.0166         0.1355        0.0

CT       =  7.802315E-03    CH        =  3.037455E-04    CL*       =  7.808775E-03    CD*       = -1.549243E-04
CT/SIGMA=  9.752064E-02    CH/SIGMA=  4.398933E-03    CL*/SIGMA=  8.759368E-02    CD*/SIGMA= -1.745775E-03
CC       =  3.612363E-04    CD*/SIGMA=  4.070614E-03

     LIFT          =  20824.746  POUNDS      X FORCE     =    1764.641  POUNDS      RESULTANT  =  20830.715  POUNDS
     DRAG          =   -413.156  POUNDS      Y FORCE     =    -275.744  POUNDS      ROLL MOM   =  -2859.685  FT-POUNDS
     HORSEPOWER    =   1269.161              Z FORCE     = -20753.961  POUNDS      PITCH MOM  = -10650.344  FT-POUNDS
     EQUIV DRAG    =   6482.754  POUNDS      EQUIV L/D   =       3.212              EQUIV F.A. =    562.175  SQ. FEET
     ALPHA(S)      =      3.723  DEGREES     THRUST      =   20807.523  POUNDS      TORQUE     =  25846.914  FT-POUNDS
     ALPHA(C)      =     -3.807  DEGREES     H FORCE     =     970.061  POUNDS      PROFILE HP =    434.670
     LAT. DIS.     =     -0.512  PERCENT     V(ACTUAL)   =      60.000  KNOTS       LONG. DIS. =     -1.913  PERCENT
                                             SHEARS HUB PITCH MOMENT = -14468.50    FT-LBS
                                             SHEARS HUB ROLL MOMENT  =  -1524.55    FT-LBS
                                             MAJOR ITERATIONS USED =    4
*****************************************************************************************************************
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6. Flapping Solution

The next page contains a sample printout of the converged flapping solution. The first item tc appear are the flapping values at the PSI equal zero azimuthal position for each revolution prior to the converged revolution on the final iteration. The values for flapping angle and its first two derivatives are expressed in radians.

The second part of this printout is the actual flapping values for the converged revoltion. The difference between the flapping angles and rates between the PSI equal zero and 360 degree position must be less than the tolerances entered in variables 101 and 102. The numbers here are also in radians. The last item is a Fourier coefficient series for the flapping angle and it is calculated in degrees. All calculations are done in respects to the shaft axis. This is PRINT Option 10.

REV	BETA(0)	BETA*(0)	BETA**(0)
1	0.1612209	-0.0006631	-0.0801615

EQUILIBRIUM SOLUTION REV = 2

PSI	BETA	BETA*	BETA**
0	0.1611688	-0.0006371	-0.0802611
15	0.1582690	-0.0213865	-0.0781108
30	0.1500716	-0.0406762	-0.0723564
45	0.1369925	-0.0584694	-0.0651056
60	0.1196410	-0.0733277	-0.0522801
75	0.0988810	-0.0843601	-0.0339573
90	0.0758699	-0.0902743	-0.0106493
105	0.0521555	-0.0900062	0.0152746
120	0.0293807	-0.0829859	0.0417729
135	0.0093257	-0.0693465	0.0658845
150	-0.0063775	-0.0499314	0.0846316
165	-0.0164170	-0.0263256	0.0961479
180	-0.0199544	-0.0005439	0.0993155

PSI	BETA	BETA*	BETA**
180	-0.0199544	-0.0005439	0.0993155
195	-0.0167111	0.0251794	0.0944388
210	-0.0069763	0.0487640	0.0821527
225	0.0084440	0.0683650	0.0637284
240	0.0283097	0.0825296	0.0409762
255	0.0510662	0.0903229	0.0161110
270	0.0749924	0.0914150	-0.0086743
285	0.0983567	0.0860550	-0.0312491
300	0.1155645	0.0750349	-0.0500851
315	0.1372783	0.0595151	-0.0642691
330	0.1504920	0.0408531	-0.0734946
345	0.1585612	0.0204393	-0.0787464
360	0.1611680	-0.0006382	-0.0802590

FOURIER COEFFICIENTS (WITH RESPECT TO THE SHAFT)

BETA (DEG) = A0-A1*COS(PSI)-B1*SIN(PSI)-A2*COS(2*PSI)-B2*SIN(2*PSI)......

A0	A1	A2	A3	A4	A5	A6
4.1835E 00	-5.1922E 00	1.3858E-01	3.7765E-03	-3.8579E-04	-1.5728E-04	-7.9641E-05
	B1	B2	B3	B4	B5	B6
	-1.8901E-02	1.6657E-02	6.8623E-03	1.8390E-04	3.0041E-05	-7.6532E-05

7. Force Integration

The next table is a sample Force Integration Output. This is PRINT Option 100. The forces are a printout for one blade only at a particular azimuthal position. CQ, CQL and CQD are the Coefficients of Torque, Torque due to Lift and Torque due to Drag. CQ is calculated from CQ = CQD - CQL. CX, CY and CZ are all related to forces in the shaft axis reference system. CMHS is the Coefficient of Pitching Moment due to aerodynamic, inertia and hub elastic restraint moments about the Shaft Axis and CLHS is the Coefficient of Rolling Moment due to these same forces. In the printout the (B) character is the number of blades, which in this example is four. SIG is the solidity of the rotor system. MAX B*CQD/SIGMA is a blade stall indicator. It is calculated by determining the first azimuthal station between the PSI equal 180 degree and 360 degree position that has a value of CQD greater than the value of CQD at the PSI equal 180 degrees azimuthal position.

FORCE INTEGRATION

PSI	CC	CQL	CQC	CZ	CX	CY	CMHS	CLFS
15	8.7047E-05	-5.3848E-05	3.3199E-05	-2.1938E-03	3.0123E-04	-2.2865E-04	-1.7954E-04	-4.8107E-05
30	5.8576E-05	-2.2839E-05	3.5739E-05	-2.1772E-03	2.3518E-04	-2.5107E-04	-1.5615E-04	-9.0152E-05
45	3.3397E-05	3.9450E-06	3.7342E-05	-2.1242E-03	1.6532E-04	-2.4881E-04	-1.1976E-04	-1.1976E-04
60	1.3576E-05	2.4695E-05	3.8271E-05	-2.0638E-03	1.0287E-04	-2.2709E-04	-7.6551E-05	-1.3259E-04
75	-4.2579E-06	3.9579E-05	3.9536E-05	-2.0289E-03	5.3344E-05	-1.9408E-04	-3.4142E-05	-1.2742E-04
90	-8.5750E-06	4.9028E-05	4.0453E-05	-2.0257E-03	1.7920E-05	-1.5403E-04	-1.3537E-10	-1.0679E-04
105	-1.2459E-05	5.2720E-05	4.0260E-05	-2.0482E-03	-3.8206E-06	-1.0967E-04	2.0545E-05	-7.6675E-05
120	-1.0206E-05	4.9335E-05	3.9128E-05	-2.0790E-03	-1.3777E-05	-6.2600E-05	2.5934E-05	-4.4919E-05
135	2.2966E-07	3.7633E-05	3.7863E-05	-2.1028E-03	-1.3753E-05	-1.3981E-05	1.8857E-05	-1.8657E-05
150	1.8757E-05	1.7279E-05	3.6036E-05	-2.0967E-03	-4.0616E-06	3.3779E-05	5.2024E-06	-3.0036E-06
165	4.3346E-05	-9.8276E-06	3.3518E-05	-2.0567E-03	1.4365E-05	7.6855E-05	-8.0343E-06	2.1528E-06
180	7.0767E-05	-4.0405E-05	3.0362E-05	-1.9830E-03	3.9575E-05	1.1188E-04	-1.5161E-05	6.7355E-11
195	9.8732E-05	-7.1089E-05	2.7643E-05	-1.8950E-03	6.9850E-05	1.3832E-04	-1.3524E-05	-3.6235E-06
210	1.2479E-04	-9.9211E-05	2.5581E-05	-1.8009E-03	1.0414E-04	1.5525E-04	-4.4115E-06	-2.5469E-06
225	1.4691E-04	-1.2303E-04	2.3880E-05	-1.7138E-03	1.4078E-04	1.6125E-04	7.6843E-06	7.6842E-06
240	1.6406E-04	-1.4162E-04	2.2447E-05	-1.6461E-03	1.7952E-04	1.5747E-04	1.6271E-05	2.8182E-05
255	1.7650E-04	-1.5492E-04	2.1579E-05	-1.6106E-03	2.1926E-04	1.4397E-04	1.5031E-05	5.6095E-05
270	1.8439E-04	-1.6283E-04	2.1558E-05	-1.6120E-03	2.5928E-04	1.2112E-04	6.4878E-10	8.5168E-05
285	1.8770E-04	-1.6554E-04	2.2158E-05	-1.6545E-03	2.9744E-04	8.9319E-05	-2.8877E-05	1.0777E-04
300	1.8620E-04	-1.6279E-04	2.3413E-05	-1.7362E-03	3.3381E-04	4.8128E-05	-6.7752E-05	1.1735E-04
315	1.7860E-04	-1.5363E-04	2.4968E-05	-1.8445E-03	3.6279E-04	-2.4277E-06	-1.0992E-04	1.0992E-04
330	1.6451E-04	-1.3781E-04	2.6697E-05	-1.9696E-03	3.8123E-04	-6.2955E-05	-1.4790E-04	8.5390E-05
345	1.4333E-04	-1.1448E-04	2.8855E-05	-2.0771E-03	3.7764E-04	-1.2611E-04	-1.7493E-04	4.6874E-05
360	1.1726E-04	-8.5470E-05	3.1813E-05	-2.1531E-03	3.5005E-04	-1.8527E-04	-1.8616E-04	2.0091E-05
AVERAGE	9.0309E-05	-5.9380E-05	3.0929E-05	-1.9456E-03	1.6542E-04	-2.6224E-05	-5.0553E-05	-5.3268E-06
(B) * AVE.	3.6124E-04	-2.3752E-04	1.2372E-04	-7.7822E-03	6.6170E-04	-1.0490E-04	-2.0221E-04	-2.1307E-05
(B)*AV/SIG	4.0706E-03	-2.6765E-03	1.3941E-03	-8.7695E-02	7.4564E-03	-1.1820E-03	-2.2786E-03	-2.4010E-04

MAX B*CQC/SIGMA = 0.001301 AT PSI = 345

8. Harmonic Analysis of Z Force

The following is a harmonic analysis of the forces in the Z or shaft axis direction. Z force is positive in the downward direction. This is PRINT Option 1000.

HARMONIC ANALYSIS OF DIMENSIONAL CZ

CZ = A0+A1*COS(PSI)+B1*SIN(PSI)+A2*COS(2*PSI)+B2*SIN(2*PSI).....

A0	A1	A2	A3	A4	A5	A6
-4.7E 02	-2.3E 02	-2.4E 02	-1.7E 01	8.8E 00	-1.1E 00	3.0E 00
	B1	B2	B3	B4	B5	B6
	-3.8E 02	-5.7E 00	-4.1E 01	-2.7E 00	-3.5E-01	6.5E 00

9. Converged Blade Analysis

The next four pages contain the sample overall summary of events occuring on the blade at each azimuthal and radial position. This is PRINT Option 1. Variable 121, PPSI, controls the azimuthal intervals that are printed out. The output items are as follows.

a. X - Center location of the blade segment

b. ALPHA - Angle-of-Attack

c. MACH - Local Mach number

d. CL - Local Coefficient of Lift

e. CD - Local Coefficient of Drag

f. PHI - Local Inflow Angle

g. L(LB/IN) - Lift produced per inch on segment

h. Sweep - Sweep Angle of airflow

PSI = 15 DEGREES

X	ALPHA	MACH	CL	CD	PHI	L(LB/IN)	SWEEP
0.0953	-0.323	0.121	0.0	0.009	-11.545	-0.003	46.11
0.1727	4.593	0.158	0.565	0.011	-8.464	2.135	33.27
0.2507	7.387	0.200	0.819	0.012	-6.377	6.872	25.56
0.3500	7.999	0.257	0.883	0.013	-4.662	12.261	19.58
0.4500	7.559	0.316	0.851	0.013	-3.543	17.925	15.76
0.5305	6.902	0.364	0.933	0.013	-2.901	26.562	13.63
0.5911	6.140	0.401	0.861	0.013	-2.518	29.715	12.36
0.6511	5.665	0.438	0.816	0.013	-2.202	33.530	11.31
0.7111	4.372	0.474	0.670	0.012	-1.934	32.349	10.43
0.7711	4.074	0.511	0.646	0.012	-1.704	38.903	9.67
0.8311	3.949	0.548	0.665	0.014	-1.504	46.011	9.01
0.8923	1.503	0.586	0.269	0.010	-1.327	19.618	8.43
0.9409	1.122	0.619	0.228	0.010	-1.201	18.383	28.01
0.9641	1.385	0.630	0.270	0.010	-1.145	22.777	27.63
0.9850	1.924	0.643	0.0	0.011	-1.097	-0.018	27.67

PSI = 30 DEGREES

X	ALPHA	MACH	CL	CD	PHI	L(LB/IN)	SWEEP
0.0953	1.807	0.131	0.0	0.010	-9.539	-0.003	36.61
0.1727	5.967	0.172	0.670	0.011	-6.601	2.996	26.89
0.2507	7.691	0.216	0.851	0.013	-4.711	8.333	21.01
0.3500	7.853	0.274	0.868	0.013	-3.169	13.757	16.36
0.4500	7.174	0.334	0.827	0.013	-2.156	19.522	13.34
0.5305	6.410	0.383	0.885	0.013	-1.570	27.912	11.61
0.5911	5.590	0.420	0.803	0.013	-1.219	30.486	10.57
0.6511	5.072	0.457	0.750	0.013	-0.927	33.686	9.71
0.7111	3.742	0.494	0.596	0.011	-0.678	31.227	8.98
0.7711	3.420	0.531	0.581	0.012	-0.464	37.781	8.35
0.8311	3.274	0.568	0.589	0.013	-0.277	43.884	7.80
0.8923	0.807	0.606	0.182	0.010	-0.111	14.246	7.31
0.9409	0.627	0.636	0.162	0.010	0.007	13.962	26.96
0.9641	0.885	0.650	0.203	0.010	0.060	18.263	26.81
0.9850	1.423	0.663	0.0	0.011	0.109	0.002	26.68

PSI = 45 DEGREES

X	ALPHA	MACH	CL	CD	PHI	L(LB/IN)	SWEEP
0.0953	3.356	0.139	0.0	0.010	-7.587	-0.003	27.39
0.1727	6.679	0.182	0.744	0.012	-4.860	3.777	20.36
0.2507	7.909	0.228	0.873	0.013	-3.156	9.619	16.09
0.3500	7.721	0.288	0.854	0.013	-1.772	15.001	12.67
0.4500	6.650	0.350	0.835	0.013	-0.657	20.791	10.42
0.5305	5.991	0.399	0.844	0.012	-0.324	28.882	9.12
0.5911	5.117	0.436	0.753	0.012	-0.003	30.819	8.33
0.6511	4.561	0.474	0.692	0.012	0.265	33.389	7.67
0.7111	3.198	0.511	0.537	0.011	0.494	30.145	7.11
0.7711	2.692	0.548	0.518	0.012	0.692	35.924	6.63
0.8311	2.688	0.585	0.518	0.012	0.864	40.983	6.20
0.8923	0.198	0.623	0.100	0.010	1.019	8.252	5.82
0.9409	0.177	0.654	0.097	0.010	1.129	8.678	25.55
0.9641	0.433	0.668	0.137	0.010	1.178	13.052	25.43
0.9850	0.972	0.681	0.0	0.011	1.220	0.023	25.33

PSI = 60 DEGREES

X	ALPHA	MACH	CL	CD	PHI	L(LB/IN)	SWEEP
0.0953	4.474	0.144	0.0	0.011	-5.828	-0.003	18.33
0.1727	7.208	0.190	0.800	0.012	-3.329	4.428	13.72
0.2507	8.087	0.238	0.893	0.013	-1.794	10.671	10.93
0.3500	7.640	0.299	0.845	0.013	-0.546	15.984	8.67
0.4500	6.621	0.361	0.789	0.013	0.282	21.766	7.17
0.5305	5.686	0.411	0.812	0.013	0.766	29.537	6.29
0.5911	4.770	0.449	0.714	0.012	1.059	30.947	5.76
0.6511	4.182	0.486	0.648	0.011	1.305	32.973	5.32
0.7111	2.790	0.524	0.495	0.011	1.515	29.195	4.94
0.7711	2.424	0.561	0.468	0.011	1.697	34.033	4.61
0.8311	2.245	0.599	0.461	0.011	1.856	38.163	4.32
0.8923	-0.265	0.637	0.033	0.010	2.000	2.849	4.06
0.9409	-0.185	0.666	0.042	0.010	2.101	4.030	23.87
0.9641	0.069	0.682	0.081	0.010	2.147	8.078	23.79
0.9850	0.611	0.695	0.0	0.011	2.186	0.042	23.72

PSI = 75 DEGREES

X	ALPHA	MACH	CL	CD	PHI	L(LB/IN)	SWEEP
0.0953	5.265	0.147	0.0	0.011	-4.406	-0.002	9.33
0.1727	7.612	0.195	0.842	0.013	-2.114	4.908	7.02
0.2507	8.259	0.244	0.911	0.014	-0.717	11.446	5.61
0.3500	7.639	0.306	0.850	0.013	0.419	16.816	4.47
0.4500	6.512	0.368	0.783	0.013	1.175	22.488	3.71
0.5305	5.521	0.419	0.795	0.013	1.620	30.026	3.26
0.5911	4.573	0.457	0.692	0.012	1.889	31.079	2.99
0.6511	3.961	0.495	0.622	0.011	2.115	32.730	2.76
0.7111	2.547	0.532	0.468	0.011	2.309	28.550	2.57
0.7711	2.165	0.570	0.436	0.010	2.477	32.728	2.40
0.8311	1.973	0.608	0.430	0.010	2.625	36.692	2.25
0.8923	-0.553	0.646	-0.011	0.011	2.757	-0.911	2.11
0.9409	-0.433	0.677	0.003	0.011	2.852	0.327	22.02
0.9641	-0.178	0.692	0.042	0.010	2.894	4.284	21.98
0.9850	0.368	0.705	0.0	0.011	2.930	0.060	21.94

PSI = 90 DEGREES

X	ALPHA	MACH	CL	CD	PHI	L(LB/IN)	SWEEP
0.0953	5.785	0.148	0.0	0.011	-3.445	-0.002	0.34
0.1727	7.919	0.197	0.874	0.013	-1.312	5.184	0.26
0.2507	8.436	0.246	0.931	0.014	-0.014	11.854	0.20
0.3500	7.710	0.308	0.861	0.013	1.040	17.300	0.16
0.4500	6.523	0.371	0.787	0.013	1.742	22.936	0.13
0.5305	5.496	0.422	0.793	0.013	2.155	30.376	0.12
0.5911	4.527	0.460	0.687	0.012	2.406	31.280	0.11
0.6511	3.897	0.498	0.614	0.011	2.616	32.768	0.10
0.7111	2.468	0.536	0.460	0.011	2.797	28.407	0.09
0.7711	2.075	0.574	0.425	0.010	2.954	32.298	0.09
0.8311	1.872	0.612	0.420	0.011	3.091	36.256	0.08
0.8923	-0.664	0.650	-0.028	0.011	3.215	-2.465	0.08
0.9409	-0.557	0.681	-0.017	0.011	3.303	-1.641	20.07
0.9641	-0.302	0.696	0.021	0.011	3.343	2.267	20.07
0.9850	0.249	0.709	0.0	0.011	3.377	0.071	20.07

	PSI = 105 DEGREES							PSI = 120 DEGREES						
X	ALPHA	MACH	CL	CD	PHI	L(LB/IN)	SWEEP	ALPHA	MACH	CL	CD	PHI	L(LB/IN)	SWEEP
0.0953	6.050	0.147	0.0	0.011	-3.023	-0.002	8.67	6.040	0.143	0.0	0.011	-3.148	-0.002	17.75
0.1727	6.133	0.155	0.898	0.013	-0.986	5.234	6.51	6.236	0.190	0.909	0.014	-1.151	5.037	13.26
0.2507	6.614	0.244	0.951	0.015	0.252	11.568	5.20	6.779	0.238	0.968	0.015	0.063	11.632	10.55
0.3500	7.655	0.306	0.674	0.013	1.255	17.356	4.14	8.048	0.303	0.888	0.013	1.043	16.929	8.36
0.4500	6.640	0.369	0.758	0.013	1.922	23.036	3.44	6.642	0.363	0.815	0.013	1.690	22.696	6.91
0.5305	5.596	0.420	0.804	0.013	2.314	30.515	3.02	5.796	0.413	0.825	0.013	2.068	30.309	6.06
0.5911	4.615	0.458	0.657	0.012	2.551	31.460	2.77	4.613	0.451	0.719	0.012	2.296	31.511	5.55
0.6511	3.975	0.496	0.624	0.011	2.750	33.015	2.56	4.169	0.469	0.647	0.011	2.487	33.269	5.12
0.7111	2.537	0.534	0.468	0.011	2.920	28.705	2.38	2.729	0.527	0.489	0.011	2.650	29.178	4.75
0.7711	2.136	0.572	0.433	0.010	3.066	32.680	2.22	2.322	0.565	0.455	0.011	2.791	33.524	4.44
0.8311	1.926	0.610	0.425	0.011	3.158	36.531	2.08	2.107	0.603	0.444	0.011	2.915	37.194	4.16
0.8923	-0.616	0.649	-0.021	0.011	3.315	-1.784	1.96	-0.436	0.641	0.007	0.010	3.026	0.676	3.91
0.9409	-0.599	0.679	-0.017	0.011	3.358	-1.641	18.13	-0.448	0.672	0.001	0.011	3.105	0.173	16.27
0.9641	-0.303	0.694	0.021	0.011	3.435	2.253	18.17	-0.190	0.687	0.040	0.010	3.140	4.068	16.35
0.9650	0.253	0.707	0.0	0.011	3.467	0.072	18.20	0.369	0.700	0.0	0.010	3.171	0.060	16.42

	PSI = 135 DEGREES							PSI = 150 DEGREES						
X	ALPHA	MACH	CL	CD	PHI	L(LB/IN)	SWEEP	ALPHA	MACH	CL	CD	PHI	L(LB/IN)	SWEEP
0.0953	5.706	0.137	0.0	0.011	-3.756	-0.002	26.92	4.968	0.130	0.0	0.011	-4.726	-0.002	36.23
0.1727	8.197	0.182	0.905	0.014	-1.768	4.596	19.94	7.973	0.171	0.680	0.013	-2.758	3.941	26.51
0.2507	6.694	0.229	0.981	0.016	-0.953	10.878	15.74	8.942	0.216	0.987	0.016	-1.531	9.740	20.67
0.3500	8.265	0.290	0.912	0.014	0.422	16.198	12.36	6.485	0.276	0.936	0.014	-0.951	15.035	16.07
0.4500	7.102	0.352	0.835	0.013	1.061	21.840	10.17	7.399	0.337	0.854	0.013	0.065	20.464	13.10
0.5305	6.072	0.402	0.853	0.013	1.431	29.627	8.69	6.359	0.386	0.685	0.013	0.451	28.377	11.39
0.5911	5.096	0.440	0.750	0.012	1.653	31.190	8.12	5.436	0.424	0.787	0.013	0.669	30.383	10.37
0.6511	4.453	0.477	0.680	0.012	1.838	33.269	7.48	4.601	0.461	0.719	0.012	0.649	32.861	9.92
0.7111	3.016	0.515	0.517	0.011	1.956	29.450	6.93	3.371	0.499	0.551	0.011	1.003	29.421	8.80
0.7711	2.607	0.553	0.468	0.011	2.132	34.370	6.46	2.963	0.536	0.525	0.012	1.135	34.812	8.18
0.8311	2.366	0.590	0.477	0.011	2.251	38.387	6.04	2.743	0.574	0.519	0.012	1.250	39.390	7.64
0.8923	-0.153	0.629	0.050	0.010	2.357	4.198	5.67	0.207	0.612	0.101	0.010	1.352	8.022	7.16
0.9409	-0.231	0.659	0.036	0.010	2.433	3.350	14.59	0.077	0.642	0.082	0.010	1.424	7.260	13.18
0.9641	0.027	0.674	0.075	0.010	2.466	7.248	14.71	0.334	0.657	0.121	0.010	1.457	11.150	13.33
0.9650	0.969	0.687	0.0	0.011	2.495	0.046	14.81	0.697	0.670	0.0	0.011	1.464	0.027	13.46

	PSI = 165 DEGREES							PSI = 180 DEGREES						
X	ALPHA	MACH	CL	CD	PHI	L(LB/IN)	SWEEP	ALPHA	MACH	CL	CD	PHI	L(LB/IN)	SWEEP
0.0953	3.704	0.115	0.0	0.010	-5.911	-0.002	45.78	1.728	0.106	0.0	0.010	-7.185	-0.002	55.72
0.1727	7.510	0.157	0.632	0.013	-4.018	3.139	32.89	6.738	0.141	0.751	0.012	-5.473	2.266	39.00
0.2507	6.896	0.200	0.982	0.016	-2.784	8.309	25.21	6.743	0.182	0.965	0.015	-4.233	6.699	29.15
0.3500	6.693	0.258	0.959	0.015	-1.792	13.504	19.28	8.682	0.238	0.980	0.016	-3.219	11.722	21.78
0.4500	7.718	0.318	0.671	0.013	-1.155	18.654	15.92	8.053	0.298	0.889	0.013	-2.969	16.612	17.26
0.5305	6.762	0.367	0.916	0.013	-0.791	26.649	13.40	7.155	0.346	0.954	0.013	-2.202	24.565	14.77
0.5911	5.621	0.405	0.626	0.012	-0.576	29.080	12.15	6.241	0.383	0.866	0.013	-1.966	27.324	13.31
0.6511	5.196	0.442	0.763	0.013	-0.399	31.988	11.12	5.634	0.420	0.809	0.013	-1.809	30.662	12.12
0.7111	3.779	0.479	0.600	0.011	-0.248	29.562	10.24	4.229	0.457	0.652	0.011	-1.660	29.268	11.13
0.7711	3.374	0.516	0.563	0.011	-0.120	34.665	9.50	3.831	0.494	0.606	0.011	-1.532	34.197	10.26
0.8311	3.156	0.554	0.563	0.012	-0.009	39.802	8.69	3.617	0.532	0.607	0.012	-1.423	39.582	9.55
0.8923	0.627	0.592	0.154	0.010	0.090	11.500	8.27	1.096	0.570	0.209	0.010	-1.326	14.402	8.91
0.9409	0.466	0.622	0.137	0.010	0.160	11.322	12.13	0.919	0.600	0.197	0.010	-1.257	15.037	11.55
0.9641	0.721	0.637	0.176	0.010	0.191	15.192	12.31	1.173	0.615	0.235	0.010	-1.227	18.882	11.75
0.9650	1.269	0.650	0.0	0.011	0.218	0.004	12.47	1.735	0.628	0.0	0.010	-1.201	-0.018	11.92

PSI = 195 DEGREES

X	ALPHA	MACH	CL	CD	PHI	L(LB/IN)	SWEEP
0.0553	-1.270	0.094	0.0	0.009	-6.507	-0.002	66.23
0.1727	5.553	0.122	0.625	0.011	-7.123	1.414	44.67
0.2507	8.461	0.161	0.934	0.014	-5.848	5.070	32.18
0.3500	9.057	0.216	0.999	0.016	-4.762	9.835	23.28
0.4500	8.404	0.275	0.927	0.014	-4.071	14.814	18.07
0.5305	7.574	0.324	0.992	0.014	-3.666	22.316	15.28
0.5911	6.690	0.361	0.908	0.013	-3.460	25.356	13.67
0.6511	6.104	0.398	0.856	0.013	-3.277	29.041	12.38
0.7111	4.714	0.435	0.706	0.012	-3.123	28.620	11.31
0.7711	4.326	0.472	0.664	0.012	-2.993	34.095	10.41
0.8311	4.120	0.509	0.650	0.012	-2.881	38.827	9.64
0.8923	1.604	0.547	0.265	0.010	-2.782	16.865	8.96
0.9409	1.413	0.578	0.254	0.010	-2.713	17.972	11.51
0.9641	1.666	0.592	0.294	0.010	-2.682	21.883	11.72
0.9650	2.228	0.605	0.0	0.010	-2.656	-0.037	11.90

PSI = 210 DEGREES

ALPHA	MACH	CL	CD	PHI	L(LB/IN)	SWEEP
-5.815	0.079	0.0	0.010	-10.001	-0.001	78.06
3.774	0.101	0.435	0.010	-9.146	0.675	49.59
8.038	0.139	0.887	0.013	-7.666	3.562	33.75
9.216	0.194	1.017	0.017	-6.396	8.008	23.34
8.764	0.253	0.967	0.015	-5.595	13.001	17.64
8.007	0.302	1.031	0.014	-5.160	20.083	14.70
7.156	0.339	0.951	0.013	-4.909	23.371	13.06
6.593	0.376	0.903	0.013	-4.708	27.281	11.75
5.218	0.413	0.760	0.012	-4.540	27.745	10.68
4.643	0.450	0.723	0.012	-4.399	33.695	9.78
4.648	0.488	0.704	0.012	-4.279	38.513	9.02
2.136	0.526	0.322	0.010	-4.173	18.871	8.36
1.912	0.556	0.309	0.010	-4.099	20.263	12.10
2.165	0.571	0.350	0.010	-4.066	24.134	12.30
2.726	0.584	0.0	0.011	-4.038	-0.054	12.47

PSI = 225 DEGREES

X	ALPHA	MACH	CL	CD	PHI	L(LB/IN)	SWEEP
0.0553	-167.175	-0.064	0.0	0.176	-167.527	-0.018	91.94
0.1727	1.072	0.079	0.144	0.010	-12.077	0.135	53.05
0.2507	7.462	0.116	0.626	0.012	-9.924	2.312	32.92
0.3500	9.358	0.172	1.032	0.017	-8.113	6.381	21.39
0.4500	9.117	0.232	1.006	0.016	-7.080	11.336	15.66
0.5305	8.435	0.281	1.078	0.014	-6.545	18.184	12.64
0.5911	7.617	0.319	0.995	0.014	-6.246	21.559	11.31
0.6511	7.079	0.356	0.949	0.013	-6.009	25.671	10.11
0.7111	5.718	0.393	0.811	0.012	-5.815	26.800	9.13
0.7711	5.359	0.431	0.779	0.013	-5.653	33.180	8.33
0.8311	5.176	0.468	0.765	0.013	-5.516	38.487	7.66
0.8923	2.666	0.507	0.378	0.010	-5.357	20.489	7.07
0.9409	2.372	0.537	0.358	0.010	-5.314	21.850	13.33
0.9641	2.627	0.552	0.399	0.010	-5.278	25.697	13.51
0.9650	3.188	0.565	0.0	0.011	-5.247	-0.068	13.66

PSI = 240 DEGREES

ALPHA	MACH	CL	CD	PHI	L(LB/IN)	SWEEP
-156.154	-0.048	0.0	0.379	-164.381	-0.029	110.24
-3.271	0.057	-0.322	0.009	-17.343	-0.155	53.15
6.728	0.095	0.749	0.012	-12.806	1.355	28.05
9.458	0.153	1.043	0.017	-9.870	5.090	16.80
9.427	0.214	1.040	0.017	-8.439	9.980	11.87
8.819	0.264	1.120	0.015	-7.751	16.654	9.59
8.035	0.302	1.035	0.014	-7.379	20.115	8.37
7.524	0.340	0.992	0.014	-7.090	24.405	7.44
6.179	0.377	0.857	0.013	-6.857	26.015	6.69
5.838	0.415	0.831	0.013	-6.665	32.771	6.08
5.671	0.453	0.820	0.013	-6.505	38.508	5.57
3.168	0.491	0.433	0.010	-6.366	22.063	5.13
2.751	0.522	0.397	0.010	-6.271	22.829	15.18
3.009	0.537	0.439	0.010	-6.229	26.670	15.31
3.571	0.550	0.0	0.011	-6.193	-0.077	15.42

PSI = 255 DEGREES

X	ALPHA	MACH	CL	CD	PHI	L(LB/IN)	SWEEP
0.0553	-140.041	-0.036	0.0	1.000	-158.223	-0.055	138.36
0.1727	-10.722	0.037	-0.493	0.013	-28.574	-0.092	42.68
0.2507	5.645	0.079	0.656	0.011	-16.207	0.837	16.66
0.3500	9.457	0.140	1.043	0.017	-11.454	4.233	9.28
0.4500	9.637	0.203	1.063	0.018	-9.526	9.074	6.36
0.5305	9.109	0.253	1.152	0.015	-8.659	15.660	5.08
0.5911	8.363	0.291	1.070	0.014	-8.204	19.277	4.41
0.6511	7.662	0.329	1.028	0.014	-7.857	23.664	3.90
0.7111	6.558	0.367	0.895	0.013	-7.580	25.638	3.49
0.7711	6.238	0.405	0.872	0.013	-7.355	32.671	3.16
0.8311	6.065	0.443	0.864	0.014	-7.169	38.722	2.89
0.8923	3.554	0.481	0.483	0.010	-7.008	23.568	2.66
0.9409	3.014	0.512	0.424	0.010	-6.898	23.387	17.50
0.9641	3.279	0.527	0.460	0.010	-6.850	27.245	17.57
0.9650	3.842	0.540	0.0	0.011	-6.809	-0.081	17.63

PSI = 270 DEGREES

ALPHA	MACH	CL	CD	PHI	L(LB/IN)	SWEEP
-126.326	-0.032	0.0	1.352	-152.606	-0.076	178.20
-16.141	0.028	-0.969	0.208	-42.412	-0.104	2.42
4.936	0.074	0.559	0.011	-16.573	0.604	0.72
9.289	0.135	1.025	0.017	-12.442	3.869	0.38
9.668	0.198	1.069	0.018	-10.152	8.721	0.25
9.251	0.249	1.168	0.015	-9.149	15.334	0.20
8.552	0.287	1.091	0.015	-8.629	19.080	0.17
8.107	0.325	1.051	0.014	-8.233	23.576	0.15
6.610	0.363	0.922	0.013	-7.921	25.755	0.14
6.514	0.401	0.902	0.013	-7.667	33.095	0.13
6.383	0.439	0.893	0.015	-7.457	39.232	0.12
3.903	0.477	0.520	0.010	-7.277	24.914	0.10
3.144	0.508	0.437	0.010	-7.154	23.729	20.10
3.415	0.523	0.481	0.010	-7.100	27.632	20.10
3.980	0.536	0.0	0.011	-7.055	-0.083	20.09

PSI = 285 DEGREES | PSI = 300 DEGREES

X	ALPHA	MACH	CL	CD	PHI	L(LB/IN)	SWEEP	ALPHA	MACH	CL	CD	PHI	L(LB/IN)	SWEEP
0.0953	-136.263	-0.038	0.0	1.114	-154.409	-0.087	136.42	-149.621	-0.052	0.0	0.617	-158.164	-0.075	109.88
0.1727	-14.106	0.039	-1.064	0.063	-31.762	-0.223	45.29	-7.995	0.060	-0.245	0.010	-22.421	-0.127	54.48
0.2507	4.393	0.080	0.501	0.011	-18.116	0.645	18.17	4.470	0.096	0.509	0.011	-15.974	0.958	29.09
0.3500	8.961	0.140	0.991	0.016	-12.502	4.013	10.01	8.667	0.153	0.956	0.015	-11.755	4.643	17.47
0.4500	9.565	0.202	1.056	0.018	-10.193	8.964	6.87	9.326	0.214	1.029	0.017	-9.688	9.777	12.35
0.5305	9.225	0.253	1.169	0.015	-9.151	15.736	5.48	9.044	0.263	1.145	0.015	-8.693	16.827	9.97
0.5911	8.575	0.290	1.093	0.015	-8.604	19.569	4.76	8.434	0.301	1.078	0.014	-8.155	20.702	8.71
0.6511	8.168	0.328	1.059	0.014	-8.185	24.206	4.20	8.057	0.338	1.050	0.014	-7.737	25.507	7.74
0.7111	6.902	0.366	0.933	0.013	-7.852	26.535	3.77	6.620	0.375	0.927	0.013	-7.401	27.790	6.96
0.7711	6.630	0.403	0.915	0.013	-7.581	34.039	3.41	6.567	0.413	0.909	0.014	-7.124	35.399	6.32
0.8311	6.519	0.441	0.906	0.016	-7.356	40.308	3.12	6.473	0.450	0.903	0.017	-6.893	41.828	5.79
0.8923	4.058	0.480	0.539	0.010	-7.163	26.108	2.87	4.033	0.488	0.538	0.010	-6.693	27.029	5.33
0.9409	3.141	0.510	0.438	0.010	-7.030	24.014	22.70	3.017	0.519	0.428	0.010	-6.555	24.284	25.02
0.9641	3.418	0.525	0.482	0.010	-6.972	27.991	22.62	3.298	0.533	0.473	0.010	-6.495	28.361	24.88
0.9850	3.983	0.538	0.0	0.011	-6.923	-0.083	22.56	3.861	0.546	0.0	0.011	-6.443	-0.080	24.76

PSI = 315 DEGREES | PSI = 330 DEGREES

X	ALPHA	MACH	CL	CD	PHI	L(LB/IN)	SWEEP	ALPHA	MACH	CL	CD	PHI	L(LB/IN)	SWEEP
0.0953	-159.954	-0.067	0.0	0.303	-160.869	-0.055	92.16	-12.607	0.082	0.0	0.032	-17.138	-0.008	78.43
0.1727	-3.664	0.082	-0.364	0.009	-17.637	-0.361	53.98	-0.507	0.104	-0.025	0.009	-14.681	-0.044	50.28
0.2507	4.997	0.117	0.566	0.011	-13.711	1.590	33.73	5.697	0.139	0.641	0.011	-11.697	2.571	34.37
0.3500	8.449	0.172	0.932	0.014	-10.560	5.713	21.97	8.315	0.193	0.918	0.014	-9.174	7.147	23.82
0.4500	9.021	0.231	0.995	0.016	-8.785	11.065	16.09	8.687	0.251	0.959	0.015	-7.634	12.679	18.02
0.5305	8.746	0.280	1.112	0.015	-7.873	18.471	13.20	8.361	0.300	1.070	0.014	-6.804	20.450	15.02
0.5911	8.151	0.316	1.053	0.014	-7.364	22.438	11.62	7.752	0.336	1.016	0.014	-6.328	24.488	13.34
0.6511	7.788	0.353	1.027	0.014	-6.961	27.297	10.39	7.382	0.373	0.989	0.014	-5.946	29.303	12.01
0.7111	6.569	0.390	0.905	0.013	-6.632	29.373	9.39	6.165	0.409	0.865	0.013	-5.629	30.946	10.91
0.7711	6.327	0.427	0.885	0.014	-6.359	37.027	8.56	5.923	0.446	0.848	0.014	-5.363	36.691	10.00
0.8311	6.242	0.464	0.883	0.016	-6.128	43.645	7.87	5.838	0.483	0.846	0.014	-5.136	45.309	9.22
0.8923	3.820	0.502	0.516	0.010	-5.927	27.492	7.27	3.425	0.521	0.480	0.010	-4.937	27.539	8.55
0.9409	2.788	0.533	0.408	0.010	-5.787	24.445	26.85	2.469	0.551	0.378	0.010	-4.799	24.255	28.08
0.9641	3.070	0.547	0.453	0.011	-5.726	28.637	26.67	2.749	0.565	0.423	0.010	-4.738	28.561	27.87
0.9850	3.629	0.560	0.0	0.011	-5.673	-0.075	26.52	3.302	0.578	0.0	0.011	-4.685	-0.066	27.69

PSI = 345 DEGREES | PSI = 360 DEGREES

X	ALPHA	MACH	CL	CD	PHI	L(LB/IN)	SWEEP	ALPHA	MACH	CL	CD	PHI	L(LB/IN)	SWEEP
0.0953	-7.201	0.097	0.0	0.010	-15.339	-0.003	66.69	-3.235	0.110	0.0	0.009	-13.455	-0.003	56.06
0.1727	1.868	0.124	0.230	0.010	-12.418	0.522	45.20	3.659	0.142	0.422	0.010	-10.398	1.279	39.43
0.2507	6.380	0.161	0.713	0.011	-9.862	3.853	32.67	6.953	0.182	0.773	0.012	-8.101	5.332	29.55
0.3500	8.223	0.216	0.907	0.014	-7.706	8.819	23.68	8.124	0.237	0.897	0.013	-6.191	10.576	22.12
0.4500	8.327	0.273	0.919	0.014	-6.339	14.423	18.40	7.946	0.295	0.877	0.013	-4.957	16.109	17.55
0.5305	7.908	0.321	1.028	0.014	-5.578	22.677	15.56	7.413	0.343	0.981	0.014	-4.257	24.781	15.02
0.5911	7.261	0.358	0.970	0.014	-5.134	26.541	13.93	6.711	0.380	0.917	0.013	-3.845	28.348	13.54
0.6511	6.866	0.394	0.939	0.013	-4.773	31.206	12.62	6.279	0.416	0.879	0.014	-3.505	32.622	12.33
0.7111	5.634	0.431	0.811	0.013	-4.471	32.164	11.53	5.020	0.453	0.744	0.012	-3.219	32.679	11.32
0.7711	5.380	0.467	0.789	0.013	-4.215	39.577	10.61	4.747	0.489	0.716	0.012	-2.975	39.512	10.46
0.8311	5.288	0.504	0.785	0.014	-3.995	45.868	9.82	4.640	0.526	0.723	0.016	-2.764	46.080	9.72
0.8923	2.813	0.542	0.425	0.010	-3.801	26.383	9.13	2.213	0.564	0.352	0.010	-2.577	23.751	9.07
0.9409	2.070	0.571	0.338	0.010	-3.665	23.361	28.65	1.613	0.593	0.288	0.010	-2.446	21.499	28.61
0.9641	2.345	0.586	0.382	0.010	-3.605	27.755	28.44	1.882	0.608	0.331	0.010	-2.387	25.938	28.40
0.9850	2.893	0.599	0.0	0.011	-3.553	-0.052	28.26	2.424	0.621	0.0	0.012	-2.337	-0.040	28.23

10. Harmonic of Air Loads

The next printout contains the harmonic analysis of the lift generated per inch on each rotor blade segment. This is PRINT Option 10000. The airloads are computed in two harmonic forms, both containing terms out to and including the tenth harmonic. The forms are

$$\text{Lift per Inch} = A0 - A1\cos\Psi - B1\sin\Psi - A2\cos 2\Psi - B2\sin 2\Psi - A3\cos 3\Psi - B3\sin 3\Psi \; ..... - A10\cos 10\Psi - B10\sin 10\Psi$$ and

$$\text{Lift per Inch} = A0 - C1\sin(\Psi + \phi_1) - C2\sin(2\Psi + \phi_2) - C3\sin(3\Psi + \phi_3) \; ..... - C10\sin(10\Psi + \phi_{10}).$$

The Ratio column is determined from the coefficients in Column C. From this ratio, one can immediately determine which airload harmonic is dominant and the relative relationship of this to the other harmonic coefficients.

HARMONICS OF AIR LOADS

STATION 1 A0 = -0.0185388

A	B	C	PHI	RATIO
0.0058114	-0.0290987	0.0296733	168.7057648	1.0000000
-0.0201269	-0.0076506	0.0215319	249.1871948	0.7256326
-0.0075798	0.0102900	0.0127804	-36.3760834	0.4307035
0.0019173	0.0048735	0.0052371	21.4752045	0.1764905
0.0016457	0.0019163	0.0025260	40.6547089	0.0851264
0.0018161	0.0006374	0.0019247	70.6604767	0.0648645
0.0013799	0.0001234	0.0013854	84.8918610	0.0466900
0.0016308	-0.0009104	0.0018677	119.1726837	0.0629405
-0.0000526	-0.0014860	0.0014869	182.0275879	0.0501094
0.0000777	-0.0004794	0.0004857	170.7967834	0.0163678

STATION 2 A0 = 2.1065311

A	B	C	PHI	RATIO
0.4665607	-2.8272552	2.8654928	170.6293030	1.0000000
0.3842223	0.1021613	0.3975722	75.1100006	0.1387448
0.0412583	-0.1719376	0.1768185	166.5062866	0.0617061
-0.0518297	-0.0356730	0.0629196	235.4613037	0.0219577
-0.0133265	0.0124577	0.0182426	-46.9297943	0.0063663
-0.0067163	-0.0013983	0.0068603	258.2390137	0.0023941
-0.0137545	0.0124043	0.0185217	-47.9545898	0.0064637
0.0100667	0.0237044	0.0257534	23.0097351	0.0089874
0.0264677	-0.0022998	0.0265674	94.9660645	0.0092715
0.0064641	-0.0225474	0.0234557	164.0029297	0.0081856

STATION 3 A0 = 6.1160278

A	B	C	PHI	RATIO
0.6907077	-5.7561398	5.7974300	173.1574097	1.0000000
0.1150140	0.1354709	0.1777093	40.3310547	0.0306531
-0.0053393	-0.1083109	0.1084424	182.8220673	0.0187053
-0.0165641	-0.0159713	0.0230098	226.0436707	0.0039690
-0.0029133	0.0028978	0.0041091	-45.1523743	0.0007088
0.0013191	0.0009068	0.0016007	55.4948120	0.0002761
0.0012444	-0.0000366	0.0012450	91.6824951	0.0002147
0.0000843	-0.0003298	0.0003404	165.6586761	0.0000587
-0.0000005	0.0001539	0.0001539	-0.1882620	0.0000265
0.0000840	-0.0002034	0.0002201	157.5609741	0.0000380

STATION 4 A0 = 10.8414097

A	B	C	PHI	RATIO
0.6164446	-6.7262754	6.7544622	174.7635345	1.0000000
-0.2930883	0.1327320	0.3217429	-65.6354218	0.0476341
-0.0419007	-0.0340860	0.0540141	230.8716888	0.0079968
-0.0247872	-0.0128548	0.0279222	242.5882416	0.0041339
-0.0008707	-0.0201105	0.0201293	182.4791412	0.0029802
0.0141912	0.0010902	0.0142330	85.6067963	0.0021072
-0.0009653	0.0089413	0.0089933	-6.1615915	0.0013315
-0.0037353	-0.0011640	0.0039125	252.6913452	0.0005792
0.0008729	0.0002412	0.0009056	74.5502472	0.0001341
-0.0035800	0.0006888	0.0036457	-79.1098633	0.0005397

STATION 5 A0 = 16.1947784

A	B	C	PHI	RATIO
0.3626862	-7.1265459	7.1357670	177.0865173	1.0000000
-0.3114024	0.1944090	0.3671053	-58.0233765	0.0514458
-0.1032558	-0.0126060	0.1040224	263.0393066	0.0145776
0.0755618	-0.0150281	0.0770417	101.2484741	0.0107966
-0.0024715	0.0103472	0.0106383	-13.4337721	0.0014908
0.0319176	0.0000382	0.0319176	89.9314423	0.0044729
-0.0014862	0.0059217	0.0061053	-14.0892754	0.0008556
0.0184920	0.0004020	0.0184964	88.7545776	0.0025921
-0.0018298	0.0026334	0.0032068	-34.7934418	0.0004494
0.0134738	0.0001376	0.0134745	89.4146423	0.0018883

STATICN 6 A0 = 23.7709961

A	B	C	PHI	RATIO
0.0274429	-7.6236906	7.6237392	179.7936707	1.0000000
-0.9006391	0.2562434	0.9363821	-74.1181946	0.1228245
-0.1355020	-0.1138743	0.1769975	229.9566040	0.0232166
0.0095282	-0.0167787	0.0192953	150.4087830	0.0025310
0.0000880	-0.0094386	0.0094390	179.4659424	0.0012381
-0.0118955	-0.0018567	0.0120395	261.1286621	0.0015792
-0.0002423	0.0052868	0.0052924	-2.6245661	0.0006942
-0.0065136	-0.0006836	0.0065494	264.0087891	0.0008591
-0.0002131	0.0050558	0.0050603	-2.4134903	0.0006638
0.0033125	-0.0002771	0.0033241	94.7816010	0.0004360

STATION 7 A0 = 26.5055695

A	B	C	PHI	RATIO
-0.3485193	-6.2393513	6.2490759	183.1970215	1.0000000
-1.3400717	0.3121706	1.3759508	-76.8867188	0.2201847
-0.1670687	-0.1379979	0.2166919	230.4433441	0.0346758
-0.0059609	-0.0201869	0.0210486	196.4511414	0.0033683
0.0012575	-0.0021948	0.0025295	150.1883545	0.0004048
0.0116361	-0.0005068	0.0116471	92.4938660	0.0018638
0.0024073	-0.0083405	0.0086809	163.9004822	0.0013891
0.0011396	-0.0004327	0.0012190	110.7918243	0.0001951
0.0003120	-0.0029015	0.0029182	173.8625031	0.0004670
0.0004716	-0.0002716	0.0005442	119.9330750	0.0000871

STATION 8 A0 = 29.9147339

A	B	C	PHI	RATIO
-0.8066483	-4.7207584	4.7891788	189.6965790	1.0000000
-1.7467089	0.3762742	1.7867775	-77.8431091	0.3730864
-0.1978083	-0.1310782	0.2372965	236.4693298	0.0495485
-0.0017244	-0.0276652	0.0277189	183.5665131	0.0057878
0.0084314	-0.0052728	0.0099443	122.0210419	0.0020764
0.0046946	-0.0064113	0.0079463	143.7868347	0.0016592
0.0059827	0.0014264	0.0061504	76.5897369	0.0012842
0.0056898	-0.0016484	0.0059238	106.1567535	0.0012369
0.0054092	0.0008308	0.0054726	81.2680969	0.0011427
0.0069205	-0.0011486	0.0070152	99.4233398	0.0014648

STATION 9 A0 = 28.9830322

A	B	C	PHI	RATIO
-1.4361496	-1.2663260	1.9147072	228.5956421	0.9784915
-1.9012938	0.4627401	1.9567947	-76.3211823	1.0000000
-0.2739782	0.0837021	0.2864787	-73.0117035	0.1464020
-0.0536059	-0.0473846	0.0715464	228.5250549	0.0365631
-0.0036424	0.0342192	0.0344125	-6.0758619	0.0175861
-0.0486374	-0.0091883	0.0494977	259.3017578	0.0252953
0.0084202	-0.0269197	0.0282058	162.6307220	0.0144143
-0.0112917	0.0050772	0.0123806	-65.7893524	0.0063270
0.0042988	-0.0254356	0.0257963	170.4072418	0.0131829
0.0137325	0.0077968	0.0157915	60.4138336	0.0080701

STATION 10 AO = 34.9860229

A	B	C	PHI	RATIO
-2.2796831	0.2039624	2.2887888	-84.8873291	1.0000000
-2.1698074	0.5970355	2.2504482	-74.6153717	0.9832485
-0.3524024	-0.1595188	0.3868251	245.6454926	0.1690086
0.1728295	-0.0118687	0.1732365	93.9284821	0.0756891
-0.0039592	0.0551648	0.0553067	-4.1050692	0.0241642
0.0780106	0.0224963	0.0811895	73.9137268	0.0354727
0.0065553	0.0280451	0.0288010	13.1561584	0.0125835
0.0357608	0.0012623	0.0357831	87.9783478	0.0156341
-0.0105172	0.0080913	0.0132695	-52.4273529	0.0057976
0.0129197	-0.0011896	0.0129743	95.2609558	0.0056686

STATION 11 AO = 40.3416443

A	B	C	PHI	RATIO
-3.0961714	1.2363281	3.3338842	-68.2327118	1.0000000
-2.6404209	0.6432902	2.7176542	-76.3076324	0.8151615
-0.4049954	-0.4475855	0.6036174	222.1401367	0.1810552
0.0306133	-0.0461915	0.0554150	146.4656372	0.0166217
0.1252972	-0.2158247	0.2495590	149.8625793	0.0748553
0.1024029	-0.0254310	0.1055135	103.9468384	0.0316488
0.0641405	-0.0390110	0.0750723	121.3084564	0.0225180
0.0103156	-0.0392041	0.0405385	165.2580566	0.0121595
0.0371099	-0.0429722	0.0567782	139.1867218	0.0170306
-0.0055227	-0.0281254	0.0286625	191.1092834	0.0085973

STATION 12 AO = 15.1531467

A	B	C	PHI	RATIO
-4.2959366	13.1468153	13.8309002	-18.0956421	1.0000000
-3.9540501	0.7513018	4.0247927	-79.2415466	0.2910000
-0.3706588	-0.5471836	0.6609067	214.1134033	0.0477848
-0.0164340	-0.0444608	0.0474008	200.2856598	0.0034272
-0.0054827	0.0113497	0.0126046	-25.7836151	0.0009113
0.0297508	0.0097892	0.0313200	71.7867584	0.0022645
0.0016600	0.0133093	0.0134125	7.1093483	0.0009697
0.0240062	0.0060478	0.0247563	75.8598328	0.0017899
0.0023791	-0.0078063	0.0081608	163.0503693	0.0005900
-0.0015144	-0.0044872	0.0047358	198.6494751	0.0003424

STATION 13 A0 = 14.6387329

A	B	C	PHI	RATIO
-3.0683117	12.3609266	12.7360525	-13.9405718	1.0000000
-3.6057901	-0.7387867	3.6806965	258.4208984	0.2889982
-0.1978170	-0.3508309	0.4027578	209.4165344	0.0316234
-0.0111755	-0.0461688	0.0475021	193.6071014	0.0037297
0.0133389	-0.0326380	0.0352586	157.7704163	0.0027684
-0.0020485	-0.0065694	0.0068813	197.3187408	0.0005403
0.0107518	-0.0086541	0.0138020	128.8303528	0.0010837
-0.0046484	-0.0016559	0.0049345	250.3928070	0.0003874
0.0063981	-0.0050375	0.0081432	128.2147675	0.0006394
-0.0042478	-0.0011064	0.0043895	255.4011841	0.0003447

STATION 14 A0 = 18.6674194

A	B	C	PHI	RATIO
-3.3165741	12.3558550	12.7932320	-15.0252333	1.0000000
-3.7300339	-0.7245855	3.7997599	259.0065918	0.2970133
-0.2268665	-0.3501016	0.4171804	212.9432526	0.0326095
-0.0109534	-0.0573655	0.0584019	190.8098907	0.0045651
0.0089840	-0.0269448	0.0284030	161.5604095	0.0022202
0.0008049	-0.0112847	0.0113134	175.9201355	0.0008843
0.0058211	-0.0045196	0.0073696	127.8259888	0.0005761
-0.0016236	-0.0042451	0.0045450	200.9294434	0.0003553
0.0012039	-0.0028799	0.0031214	157.3127899	0.0002440
-0.0010307	-0.0023727	0.0025869	203.4801636	0.0002022

STATION 15 A0 = -0.0176909

A	B	C	PHI	RATIO
0.0103698	-0.0756623	0.0763695	172.1959381	1.0000000
0.0104975	0.0040839	0.0112639	68.7422333	0.1474917
-0.0003934	0.0010045	0.0010788	-21.3894806	0.0141261
-0.0008102	-0.0004531	0.0009283	240.7874298	0.0121552
0.0001319	-0.0001743	0.0002186	142.8869476	0.0028622
0.0007655	0.0000467	0.0007669	86.5120850	0.0100423
-0.0000028	0.0004759	0.0004759	-0.3370049	0.0062313
0.0001418	-0.0001749	0.0002252	140.9597321	0.0029482
0.0003694	0.0000019	0.0003694	89.7012482	0.0048371
0.0002440	0.0000810	0.0002571	71.6364288	0.0033660

IV. GRP SAMPLE ANALYSIS

The GRP program was executed using data representing a relatively new rotor blade. The results were compared with results predicted by the blade's manufacturer. The rotor blade was an unsymmetrical blade. The rotor radius was divided into three sections. Sections one and three were made of the same type airfoil. The blade included a sweep tip design. The blade and helicopter configuration analyzed are typical of a helicopter that could be used by the U.S. Navy in a LAMPS type mission.

For the analysis, the blade was divided into 15 segments. The program used the manufacturer's values for the First and Second Moment of Inertia about the Flapping Hinge, vice local blade mass densities. The GRP assumed uniform inflow for all flight velocities . It used a rigid blade analysis while the actual blade does have live twist. The program was run at five different flight weights, ranging from 16,359 to 20,829 pounds. A flat plate area of 35.8 square feet was used at all speeds. The GRP was run for forward flight speeds of 40 to 160 knots at ten knot increments. The program was executed at sea level, tropical day condition. The manufacturer's predicted rotor horsepower was obtained from his Shaft Horsepower versus True Airspeed curves and was corrected to rotor horsepower by using the manufacturer's Mechanical Efficiency curves.

The results of the analysis are shown in the next several tables. Table VI illustrates a comparison of the GRP required rotor horsepower divided by the manufacturer's required rotor horsepower. The GRP agreed within an average of two percent on the entire range from 40 to 160 knots. The GRP agreed within an average of one percent for the cruise range between 70 and 140 knots. It can be seen that between 40 to 60 knots there is a much larger difference

between the two required horsepowers. It is felt that the inflow in this region is not uniform as assumed, but highly mixed and irregular. Also, the GRP results were less than the manufacturer's horsepower in the 150 to 160 knot range. This area represents the region of top speed for the helicopter, and much of the retreating blade is in the stall region. Also, it is expected that there is a change in fuselage attitude at this high speed, which would increase the flat plate area above what was used in the program. The GRP program's maximum endurance velocities agreed exactly with those predicted by the manufacturer.

TABLE I WEIGHT = 16359 LBS

VELOCITY	GRP RHP	MANUFACTURER'S RHP	RATIO(GRP/MAN)
40	1105	1152	.96
50	1006	1041	.97
60	960	973	.99
70	955	958	1.00
80	984	971	1.01
90	1047	1034	1.01
100	1142	1109	1.03
110	1273	1237	1.03
120	1438	1396	1.03
130	1643	1589	1.03
140	1893	1852	1.02
150	2300	2216	1.04
160	2567	2745	.94

TABLE II WEIGHT = 17321 LBS

VELOCITY	GRP RHP	MANUFACTURER'S RHP	RATIO(GRP/MAN)
40	1185	1247	.95
50	1075	1122	.96
60	1018	1038	.98
70	1008	1009	1.00
80	1028	1028	1.00
90	1086	1078	1.01
100	1176	1153	1.02
110	1303	1264	1.03
120	1465	1445	1.01
130	1669	1633	1.02
140	1921	1902	1.01
150	2227	2257	.99
160	2598	2791	.93

TABLE III WEIGHT = 19246 LBS

VELOCITY	GRP RHP	MANUFACTURER'S RHP	RATIO(GRP/MAN)
40	1366	1449	.94
50	1229	1301	.94
60	1148	1186	.97
70	1118	1142	.98
80	1126	1153	.98
90	1172	1199	.98
100	1255	1273	.99
110	1375	1387	.99
120	1530	1557	.98
130	1731	1746	.99
140	1983	2038	.97
150	2290	2440	.94
160	2665	-	-

TABLE IV WEIGHT = 19658 LBS

VELOCITY	GRP RHP	MANUFACTURER'S RHP	RATIO(GRP/MAN)
40	1407	1496	.94
50	1264	1340	.94
60	1178	1231	.96
70	1142	1173	.97
80	1149	1179	.98
90	1193	1221	.98
100	1274	1299	.98
110	1392	1414	.98
120	1546	1566	.99
130	1747	1773	.99
140	1999	2048	.98
150	2305	2477	.93
160	2682	-	-

TABLE V WEIGHT = 20829 LBS

VELOCITY	GRP RHP	MANUFACTURER'S RHP	RATIO(GRP/MAN)
40	1532	1627	.94
50	1370	1457	.94
60	1269	1338	.95
70	1222	1267	.96
80	1219	1258	.97
90	1256	1297	.97
100	1330	1375	.97
110	1445	1477	.98
120	1598	1638	.98
130	1798	1866	.96
140	2045	2157	.95
150	2354	2589	.91
160	2747	-	-

TABLE VI RATIO COMPARISON

	WEIGHT					RATIO
VELOCITY	16359	17321	19246	19658	20829	AVERAGE
40	.96	.95	.94	.94	.94	.95
50	.97	.96	.94	.94	.94	.95
60	.99	.98	.97	.96	.95	.97
70	1.00	1.00	.98	.97	.96	.98
80	1.01	1.00	.98	.97	.97	.99
90	1.01	1.01	.98	.98	.97	.99
100	1.03	1.02	.99	.98	.97	1.00
110	1.03	1.03	.99	.99	.98	1.00
120	1.03	1.01	.98	.99	.98	1.00
130	1.03	1.02	.99	.99	.96	1.00
140	1.02	1.01	.97	.98	.95	.99
150	1.04	.99	.94	.93	.91	.96
160	.94	.93	-	-	-	.94
AVERAGES FOR ENTIRE SPEED RANGE						
AVERAGE	1.00	.99	.97	.97	.96	.98
AVERAGES FOR CRUISE RANGE 70 - 140 KNOTS						
AVERAGE	1.02	1.01	.98	.98	.97	.99

V. CONCLUSIONS

The logic and theory used in the GRP program was investigated and found to be sound. However, there were three discrepancies in the Navy's version of the program that did require attention. The calculations in the reverse flow section on the rotor were incorrect, the calculation of the chord at the 75 percent radius position was incorrect and the original Trim Option for reducing moments would not work. All of the above discrepancies were corrected.

Three desirable features were added to the GRP program. First, the ability to analyze a rotor blade composed of more than one airfoil type was added. The program will now accept up to five different airfoil data input decks for use in analyzing a rotor system. Secondly, the program would only calculate performance in level flight. The ability to calculate performance in climbs and descents has been added. Lastly, the program will now calculate the aerodynamics for a swept tip rotor blade design.

The results of the sample analysis described in Section IV indicates that the program does produce highly accurate performance predictions. The averaged GRP rotor horsepower was within two percent of the manufacturer's data. The results were within one percent when compared in the area of normal cruise flight. The GRP, in this analysis, assumed uniform inflow, constant flat plate area and a rigid rotor blade. It is felt that while complicated, computer-time-comsuming procedures can be taken to reduce these assumptions, they are not warranted if the GRP is to be used strictly as a helicopter performance prediction program.

GRP COMPUTER PROGRAM

```
C   AIR-530132B  UNGER     UG   23541     RM 904
C      FOR INFO, CALL GEORGE UNGER OR HIS FAITHFUL ORTHODOX COMPANION
C      STEVEN AT X23544, PROVIDED THEY HAVE NOT BEEN LIFTED, SHIFTED,
C      RIFTED, OR OTHERWISE FOUND BETTER JOBS....
C
C  MODIFIED BY LT. JIM LOISELLE, USN, 1977,
C  NAVAL POSTGRADUATE SCHOOL, MONTEREY, CALIF.
C
      EQUIVALENCE      (V(1),OMEGAR),   (V(2),R),         (V(3),SPSD),
     1(V(4),RHO),      (V(5),XNB),
     1(V(6),VEL),      (V(7),ER),       (V(8),DX),
     2(V(23),TW),      (V(38),XMASS),   (V(53),C),        (V(68),DPSI),
     3(V(69),FTRI),    (V(70),BIN),     (V(71),BPIN),     (V(72),BPPIN),
     4(V(73),XITLIM),  (V(74),RL),      (V(75),RD),       (V(76),XLTOL),
     5(V(77),XDTOL),   (V(78),FMOM),    (V(79),SMOM),     (V(80),AG),
     6(V(81),BGL),     (V(82),CG),      (V(83),TD3L),     (V(84),DELD),
     7(V(85),A1S),     (V(86),B1S),     (V(87),T75),      (V(88),LAMBDA),
     8(V(89),MUL),     (V(90),UIN),     (V(91),SKIPIN),   (V(92),TWIST)
      EQUIVALENCE      (V(93),XNSEG),                     (V(96),TOP),
     9(V(97),PCNV),    (V(98),PRINT),   (V(99),XEND),     (V(100),ABIT),
     1(V(101),BTOL),   (V(102),BPTOL),  (V(103),SPAR),    (V(104),A2S),
     A(V(105),B2S),    (V(106),RSL),    (V(107),SYM),     (V(108),SFH),
     B(V(109),FDMP),   (V(110),ALOPT),  (V(111),ALL),     (V(112),RA1S),
     C(V(113),RB1S),   (V(114),TOLAB),  (V(115),TD3B),    (V(116),PHD3B),
     D(V(117),LAML),   (V(118),UVL),    (V(120),BSPL),    (V(121),PPSI),
     E(V(122),ATEST),  (V(123),IGC),    (V(124),PLOD),    (V(126),PCR),
     F(V(138),INPL),   (V(139),PSIS),   (V(140),PHIS),    (V(141),THFS),
     G(V(142),FSCG),   (V(143),FSMR),   (V(144),WLCG),    (V(145),WLMR),
     H (V(146),VELY),  (V(158), TIPSWP),(V(159), TPSWST),
     I(V(94), RCFPM),  (V(95),FPAREA),  (V(156),HIALFA),(V(157),LOALFA),
     J(V(161),RB),     (V(147),SYMSPR),    (V(160),TRIM)
      EQUIVALENCE (XCQ,TF(1)),(TF(2),XCQL),(TF(3),XCQD),(TF(4),XCZ),(TF(
     15),XCX),(TF(6),XCY),(TF(7),XHM),(TF(8),XHL),
     2(CQ(1),FC(1,1)),(FC(1,2),CQL(1)),(FC(1,3),CQD(1)),(FC(1,4),CZ(1)),
     3(FC(1,5),CX(1)),(FC(1,6),CY(1)),(FC(1,7),HM(1)),(FC(1,8),HL(1))
      DIMENSION HM(73),HL(73),AV(9), RB(15)
      DIMENSION       X(15),XX(15),DX(15),NN(15),C(15),CR(15),XMASS(15)
     1, TW(15), CLT(5,15,100),CDT(5,15,100), PHI(73,15),
     2     UP(15),UT(15),U(15),         AL(73,15),XMACH(73,15),CL(73,15),
     3CD(73,15),THETAR(15),       LOAD(73,15),XLFC(15),B(73),BP(73),BPP(
     373),IPSI(73),    BO(20),BPO(20),BPPO(20),BUF1(10),BUF2(10),BUF3(10),
     4BUF4(10),BUF5(10),UCD(15),CRDX(15),CQL(73 ),CQD(73 ),CQ(73 ),CZ(73
     5 ),CX(73 ),CY(73 ),XR(73 ),CP(73 ),BD(73 ),H(10),          CDX(15),
     6BSCLT(1,5,71),BSCDT(1,5,71)
```

```
      DIMENSION SWPCOS(15),UR(15), UTUR(15),SWEEP(73,15)
      DIMENSION XDA(73,15),XLAO(15),XLA(15,18),XLB(15,18),DUM(73)
      DIMENSION V(200),TF(9), FC(73,9),XMESS(7)
      LOGICAL D3B,CONV,SHIN,MCONV,A1B1,ALFA,PRNT,      USVL,TEST
      REAL MU,LAMBDA,MUSQ,MUL,LOAD,LAMI,      IGC,LRF,LATD,LONGD,INPL
      REAL MUY,LMR,MG
      INTEGER CASE
      JOY = 0
      JEB = 0
C*****READ IN BLADE CURVE DATA ***********************************
 2000 READ(5,169) WBLADE
      READ(5,69) NBLDAT
      IF (WBLADE .EQ. 0.) GO TO 10
      WRITE(6,173)
      WRITE(6,79) NBLDAT
 10   DO 63 N=1, NBLDAT
      READ(5,69) NZ
      IF (WBLADE .NE. 0.) WRITE(6,79) NZ
      DO 61 I=1,NZ
      READ(5,69)  J, (CLT(N,I,K), K=1,J)
      IF (WBLADE .NE. 0.) WRITE(6,79) J, (CLT(N,I,K),K=1,J)
   61 CONTINUE
      READ(5,69) NZ
      IF (WBLADE .NE. 0.) WRITE(6,79) NZ
      DO 63 I=1,NZ
      READ(5,69)  J, (CDT(N,I,K), K=1,J)
      IF (WBLADE .NE. 0.) WRITE(6,79) J, (CDT(N,I,K),K=1,J)
   63 CONTINUE
C*****ZERO OUT LOADER AREA*****************************************
      DO 59 I=1,200
   59 V(I)=0.
C SET UP CONSTANTS AND AUTOMATIC INPUT
      PI = 3.14159265
      TWOPI = 6.28318531
      RC = 57.2957795
      XXXXX = 1.0
      BTOL=.001
      BPTOL=.001
      XLTOL=100.
      XDTOL=50.
      TOLAB=.25
      BGL=90.
      G=32.2
      IGC=1.
      FTRL = 15.0
      DPSI = 15.0
      BIN = .000001
      BPIN = .000001
      XITLIM = 15.0
```

```
      BPPIN = .000001
      XNSEG = 15.0
      B1S = 7.53
      A1S = -1.2
      SKIPIN = 1.0
      PCNV = 1.0
      CASE=0
      DO 9000 I=1,15
 9000 RB(I)=1.0
      HIALFA=30.
      LOALFA=-30.
      TPSWST=16.0
      T75= 5.0
      LAMBDA=-.0200
C *****************************************************************
C**** READ IN CASE DATA *********************************************
 1000 CALL LOADED(V)
      CASE=CASE + 1
      NTPST=TPSWST
      TIPSW=TIPSWP/RC
      I=SPAR
      DO 9002 J=1,I
 9002 RB(J)=0.0
      MOMITN=0
      RD=-ABS(RD)
      IF(FPAREA .NE. 0.) RD=-.5*RHO*(VEL*1.689)**2*ABS(FPAREA)
      IF (ABIT.EQ.0.) GO TO 999
      A1S=0.
      B1S=0.
999   NPRNT = PRINT
      DO 810  II = 1,7
      NPRNT = NPRNT -10**(7 - II)
      IF (NPRNT)  811,812,812
 811  XMESS(II) = 0.0
      NPRNT = PRINT
      GO TO 810
 812  XMESS(II) = 1.0
 810  CONTINUE
      SKIP = -1.0
      IF (SKIPIN.NE.0.)  SKIP = 1.0
  70  IF (JEB.GT.0) GO TO 1600
C**** PRINT HEADING BEFORE EACH CASE *******************************
      WRITE (6,80)
C SET UP CONTROL VARIABLES ACCORDING TO INPUT OPTIONS
      TOLAB = ABS(TOLAB)
      SHIN=XITLIM.LT.0.
      A1B1=ABIT.NE.0.
      IF(TOP.NE.0.) ATEST=-50.
      ALFA=XITLIM.NE.0..AND.(ALOPT.NE.0..OR.TOP.NE.0.)
```

```
      PRNT=TRAN.NE.0.
      USVL=UVL.NE.0.
      D3B=TD3B.NE.0.
      IF(PPSI.EQ.0.) PPSI=DPSI
      IF(ATEST.EQ.0.) ATEST=5.
      NSEG=XNSEG
      PC=PCR*RC
      XDPSI=DPSI/RC
      K=360.0/DPSI+.1
      KP1=K+1
      OM=OMEGAR/R
      R4 = R**4
      R5 = R**5
      OMS = OM**2
      FAC=2./(RC*OM)
      ITLIM=ABS(XITLIM)
      ITN=0
      NSPAR=ABS(SPAR)
      NTRL=FTRL
      IF(SHIN) NTRL=1
      TEST=.TRUE.
      MCONV=.TRUE.
      IDPSI=DPSI
      IPSI(1)=0
      DO 997 I=2,KP1
  997 IPSI(I)=IPSI(I-1)+IDPSI
      NB=XNB
C*****ZERO OUT LAMBDA*S IF NCT TO BE USED  ***************************
      IF(USVL) GO TO 551
      DO 550 I=2,KP1
      DO 550 J=1,NSEG
  550 XDA(I,J)=0.
C**** READ HARMONICS OF LAMBDA IF DESIRED ***************************
  551 IF(LAML.EQ.0.) GO TO 504
      LAML=0.
      READ(5,500) NHARM
      DO 503 I=1,NSEG
      READ(5,501) XLAO(I)
      READ(5,502) (XLA(I,J),J=1,NHARM)
  503 READ(5,502) (XLB(I,J),J=1,NHARM)
C**** COMPUTE VARIABLE LAMBDAS IF TO BE USED ************************
  504 IF(.NOT.USVL) GO TO 507
      XI=0.
      DO 506 I=2,KP1
      XI=XI+XDPSI
      DO 506 J=1,NSEG
      XDA(I,J)= -XLAO(J)
      ARG=0.
      DO 506 L=1,NHARM
```

```
      ARG=ARG+XI                                                        GRP01930
  506 XDA(I,J)=XDA(I,J)-XLA(J,L)*COS(ARG)-XLB(J,L)*SIN(ARG)             GRP01940
C**** READ BIVARIANT SPAR DATA IF DESIRED *****************************GRP01950
  507 IF(BSPL.EQ.0.) GO TO 508                                          GRP01960
      BSPL=0.                                                           GRP01970
      READ(5,169) WRSPAR                                                GRP01980
      READ(5,69) NZ                                                     GRP01990
      IF (WRSPAR .EQ. 0.0) GOTO 9006                                    GRP02000
      WRITE(6,74)                                                       GRP02010
      WRITE(6,69) NZ                                                    GRP02020
 9006 DO 509 I=1,NZ                                                     GRP02030
      READ(5,69) J,(BSCLT(1,I,KK),KK=1,J)                               GRP02040
 509  IF (WRSPAR .NE. 0.0) WRITE(6,69) J,(BSCLT(1,I,KK),KK=1,J)         GRP02050
      READ(5,69) NZ                                                     GRP02060
      IF (WRSPAR .NE. 0.0) WRITE(6,69) NZ                               GRP02070
      DO 510 I=1,NZ                                                     GRP02080
      READ(5,69) J,(BSCDT(1,I,KK),KK=1,J)                               GRP02090
 510  IF (WRSPAR .NE. 0.) WRITE(6,69) J,(BSCDT(1,I,KK), KK=1,J)         GRP02100
C GRAVITY ANGLE COMPUTATIONS                                            GRP02110
  508 IF(BGL.EQ.90.0) GO TO 301                                         GRP02120
      AA=COS(AG/RC)                                                     GRP02130
      BB=COS(BGL/RC)                                                    GRP02140
      CC=COS(CG/RC)                                                     GRP02150
      AA2=AA**2                                                         GRP02160
      BB2=BB**2                                                         GRP02170
      CC2=CC**2                                                         GRP02180
      HW=SQRT(1.0+ AA2*BB2*CC2)                                         GRP02190
      HX=BB*SQRT(CC2*(AA2-1.0)+1.0)                                     GRP02200
      HY=CC*SQRT(AA2*(BB2-1.0)+1.0)                                     GRP02210
      HZ=AA*SQRT(BB2*(CC2-1.0)+1.0)                                     GRP02220
      GO TO 302                                                         GRP02230
  301 HW=1.0                                                            GRP02240
      HX=0.0                                                            GRP02250
      HY=0.0                                                            GRP02260
      HZ=1.0                                                            GRP02270
C COMPUTE X*S AND CHORDS                                                GRP02280
  302 D=ER                                                              GRP02290
      X(1)=DX(1)/2.0                                                    GRP02300
      XX(1)=X(1)+ER                                                     GRP02310
      DO 1 I=2,NSEG                                                     GRP02320
      D=D+DX(I-1)                                                       GRP02330
      X(I)=X(I-1)+(DX(I-1)+DX(I))/2.0                                   GRP02340
    1 XX(I)=X(I)+ER                                                     GRP02350
      SUM=D+DX(NSEG)                                                    GRP02360
      IF(ABS(C(1)-C(2)).GT..0000001) GO TO 199                          GRP02370
      DO 12 I=2,NSEG                                                    GRP02380
   12 C(I)=C(I-1)                                                       GRP02390
 199  DO 86 I=1,NSEG                                                    GRP02400
      IF(X(I)-.75)86,88,87                                              GRP02410
```

```
   86 CONTINUE                                                        GRP02420
   87 C75=C(I-1)+((.75-X(I-1))/(X(I)-X(I-1))*(C(I)-C(I-1)))           GRPC2430
      GO TO 89                                                        GRP02440
   88 C75=C(I)                                                        GRP02450
   89 C752=2.*C75**2                                                  GRP02460
      BG=G*R/OMEGAR**2                                                GRP02470
C PRE-COMPUTATION OF FREQUENTLY USED COMBINATIONS                      GRP02480
      XLF=RHO*OMEGAR**2/24.                                           GRP02490
      DO 2 I=1,NSEG                                                   GRP02500
      CDX(I)=C(I)**2*DX(I)                                            GRP02510
      CR(I)=C(I)/R                                                    GRP02520
      CRDX(I)=CR(I)*DX(I)                                             GRP02530
    2 XLFC(I)=XLF*C(I)                                                GRP02540
C COMPUTE 1ST AND 2ND MOMENTS                                          GRP02550
      RR2=.5*RHO*R**2                                                 GRP02560
      RR5=RR2*R**3                                                    GRP02570
      IF(SMOM.NE.0.) GO TO 96                                         GRP02580
      S=XMASS(1)/RR2*X(1)*DX(1)                                       GRP02590
      SR=S*X(1)                                                       GRPC2600
      DO 3 I=2,NSEG                                                   GRP02610
      DXD=XMASS(I)/RR2*X(I)*DX(I)                                     GRP02620
      S=S+DXD                                                         GRPC2630
    3 SR=SR+DXD*X(I)                                                  GRP02640
      SMOM=SR*RR5                                                     GRPC2650
      S=S/SR                                                          GRP02660
      FMOM=S*SMOM/R                                                   GRP02670
      GO TO 97                                                        GRP02680
   96 SR=SMOM/RR5                                                     GRPC2690
      S=FMOM*R/ SMOM                                                  GRP02700
C COMPUTE SIGMA                                                        GRPC2710
   97 RS=RSL                                                          GRP02720
      IF(RSL.EQ.0.) RS=XNB*C75/(PI*R)                                 GRP02730
C COMPUTE TWISTS                                                       GRPC2740
      IF(TWIST.EQ.0.0) GO TO 102                                      GRP02750
      DO 101 I=1,NSEG                                                 GRP02760
  101 TW(I)=(XX(I)-.75)*TWIST                                         GRPC2770
  102 HK=TWOPI*RR2*OMEGAR**2                                          GRP02780
      IF(D3B) PHD3BR=PHD3B/RC                                         GRPC2790
      XSIN=SIN(XDPSI)                                                 GRP02800
      XCOS=COS(XDPSI)                                                 GRP02810
C**** COMPUTE MU AND LAMBDA ******************************************* GRP02820
      IF(.NOT.ALFA.AND..NOT.USVL) GO TO 777                           GRP02830
      IF(UVL.LT.0.) GO TO 777                                         GRP02840
      ALLR=ALL/RC                                                     GRP02850
      CAL=COS(ALLR)                                                   GRP02860
      MU=VEL*CAL/OMEGAR*1.689                                         GRP02870
      MUSQ=MU**2                                                      GRP02880
      IF(USVL) GO TO 104                                              GRP02890
      XLMBD = MU*SIN(ALLR)/CAL-RL/(HK*2. *MU)                         GRPC2900
```

```
      IF(MU.LT..1) XLMBD = XLMBD/2.
      DO 1603 ITOM = 1,100
      LAMBDA = MU*SIN(ALLR)/CAL-RL/(CAL*2.*HK*SQRT(MU**2+XLMBD**2))
      IF(ABS(LAMBDA-XLMBD).LT..0001) GO TO 104
 1603 XLMBD = LAMBDA
      WRITE (6,1604) LAMBDA,XLMBD
      GO TO 104
  777 IF(UIN.EQ.0.) GO TO 103
      MU = MUL
      MUSQ = MU**2
      VEL = SQRT((MUSQ+LAMBDA**2)*(OMEGAR*.5921)**2)
      GO TO 104
  103 MUSQ = (VEL/(OMEGAR*.5921))**2-LAMBDA**2
      MU = SQRT(MUSQ)
C**** COMPUTE TIP MACH NO. *******************************************
  104 XMTIP = OMEGAR/SPSD
      MUY = VELY/OMEGAR*1.689
C PRINT INPUT
      DO 198 I=1,NSEG
  198 NN(I)=I
      GO TO 1002
 1001 WRITE (6,58)
 1002 WRITE (6,200) (NN(I),I=1,NSEG)
      WRITE (6,201) (XMASS(I),I=1,NSEG)
      WRITE (6,202) (DX(I),I=1,NSEG)
      WRITE (6,203) (XX(I),I=1,NSEG)
      WRITE (6,204) (C(I),I=1,NSEG)
      WRITE (6,205) (TW(I),I=1,NSEG)
      WRITE (6,206) (RB(I), I=1,NSEG)
      RB(1)=1.0
      WRITE (6,1010) CASE
      WRITE (6,207) OMEGAR,AG,R,BGL,SPSD,CG,RHO,TD3I
      WRITE (6,208) G,ER,NB,DELD,XMTIP,SMOM,RS,SUM,FMOM,VEL,HK,IDPSI,FDM
     1P,SFH,IGC,PC,TD3B,PHD3B
      WRITE (6,225) FSCG,VELY
      WRITE (6,226) FSMR,PSIS
      WRITE (6,227) WLCG,PHIS
      WRITE (6,228) WLMR,THFS
      WRITE (6,585)
      WRITE (6,211) BTOL,BPTOL,NTRL
C**** PRINT MAJOR ITERATION OPTIONS IF USED ***************************
      IF(XITLIM .EQ.0.) GO TO 1600
      WRITE (6,38) RL,RD,ITLIM,XLTOL,XDTOL
      IF(SHIN) WRITE (6,25)
      IF(.NOT.SHIN) WRITE (6,585)
      IF(A1B1) WRITE(6,95) RA1S,RB1S,TOLAB
      IF(ALFA) WRITE(6,39) ALL
C**** SET UP CASE AND COMPUTE STARTING VALUES *************************
 1600 CONTINUE
```

```
29    LL=0
      A1R=A1S/RC
      B1R=B1S/RC
      CB=COS(B1R)
      SB=SIN(B1R)
      IF(BIN.EQ.0..OR.ITN.NE.0) GO TO 210
      B(1)=BIN
      BP(1)=BPIN
      BPP(1)=BPPIN
      BIN=0.
      GO TO 114
210   IF(PCNV.NE.0.0) GO TO 113
      GAM=5.73*C75*RHO*R**4/SMOM
      T7R=T75/RC
      HA=GAM/2.*(T7R*((1.0+MUSQ)/4.0)+LAMBDA/3.0)
      BPP(1)=MU*(8./3.*T7R+2.*LAMBDA)/(1.-.5*MUSQ)
      BP(1)=-4./3.*MU*HA/(1.+.5*MUSQ)
      B(1)=HA-BPP(1)
      GO TO 114
113   B(1)=B(KP1)
      BP(1)=BP(KP1)
      BPP(1)=BPP(KP1)
114   PSI=0.0
      LL=LL+1
      XMH3 = 0.0
      XMH5 = 0.0
      XLH1 = 0.0
      XLH2 = 0.0
      HMR = (WLMR-WLCG)/(12.*R)
      LMR = (FSCG-FSMR)/(12.*R)
      PSO = PSIS/OM
      PHSO = PHIS/OM
      THFO = THFS/OM
      FMEOR = FMOM*ER/(RHO*PI*R4)
      ERPI = ER/TWOPI
      SUM  = 0.0
      SUM1 = 0.0
      SUM2 = 0.0
      SUM3 = 0.0
      SUM4 = 0.0
      RCFPS=RCFPM/60.
C ***************************************************************************
C BEGIN CASE  *****************************************************************
      DO 30 I=2,KP1
      PSI=PSI+XDPSI
      B(I)=B(I-1)+BP(I-1)*XSIN+(1.-XCOS)*BPP(I-1)
      BD(I)=B(I)*RC
      BP(I)=BP(I-1)*XCOS+BPP(I-1)*XSIN
      YSIN=SIN(B(I))
```

```
      ZSIN=SIN(PSI)
      YCOS=COS(B(I))
      ZCOS=COS(PSI)
      CWM =(((ZCOS*HX+ZSIN*HY)*YSIN+YCCS*HZ)*BG/HW+ER*YSIN)*S
      IF(SMOM.NE.0.) CWM=CWM+YSIN*YCOS
      AM=0.0
      DO 7 IJ=1,7
    7 H(IJ)=0.0
      PSI2=2.0*PSI
C  CALCULATIONS FOR DELTA 3 BAR
      TD3=TD3L
      IF(D3B) TD3=TD3+TD3B*SIN(PSI+PHD3BR)
C BEGIN SPANWISE INTEGRATION***************************************
      DO 28 N=1,NSEG
      NB=RB(N)
      UP(N) = (LAMBDA+(ER+ X(N)*YCOS)*(PHSO*ZSIN+ THFO*ZCOS)- LMR*
     1THFO)*YCOS-X(N)*BP(I)-(MU*ZCOS-MUY*ZSIN) *YSIN
      IF(USVL) UP(N)=UP(N)-XDA(I,N)*YCOS /OMEGAR+VEL*SIN(ALL/RC)/OMEGAR
      IF (RCFPM .NE. 0.)  UP(N)=UP(N) - RCFPS*YCOS/OMEGAR
      UT(N) = (1.-PSO)*(ER+X(N)*YCOS)+(MU-HMR*THFO)* ZSIN+(MUY+LMR *PSO
     1+HMR*PHSO)*ZCOS
      UR(N) = MU*ZCOS*YCOS-(LAMBDA+(ER+X(N)*YCOS)*(PHSO*ZSIN + THFO*ZCOS
     1) - LMR*THFO)*YSIN
C  CALCULATIONS FOR TIP SWEEP
      IF (N .LT. NTPST) GOTO 9007
      URS=UR(N)*COS(TIPSW) + UT(N)*SIN(TIPSW)
      UTS=UT(N)*COS(TIPSW) - UR(N)*SIN(TIPSW)
      UT(N)=UTS
      UR(N)=URS
 9007 USQ=UP(N)**2+UT(N)**2 + UR(N)**2
      U(N)=SQRT(USQ)
      U(N) = SIGN(U(N),UT(N))
      UTUR(N) = SQRT(UT(N)**2 + UR(N)**2)
      UTUR(N)=SIGN(UTUR(N),UT(N))
      SWPCOS(N) = ABS(UT(N))/UTUR(N)
      SWEEP(I,N)=ATAN2(SQRT(1.-SWPCOS(N)**2),SWPCOS(N))*RC
      PHI (I,N) = ATAN2(UP(N),UTUR(N))*RC
 2222 XMACH(I,N)=XMTIP*U(N)
      XMACHT = ABS(XMACH(I,N))
      THETAR(N)=(TW(N)-A1S*ZCOS-B1S*ZSIN-A2S*COS(PSI2)-B2S*SIN(PSI2)-TD3
     1*BD(I)+T75)/RC
      AL(I,N) = PHI(I,N)+ATAN2(ABS(SWPCOS(N))*SIN(THETAR(N)),COS(THETAR(
     1N)))*RC
      ABAL=ABS(AL(I,N))
      IF(ABAL.GT.180.) AL(I,N)=SIGN(ABAL-360.,-AL(I,N))
      ALRAD=AL(I,N)/RC
      ALTAB=ABS(AL(I,N))
      IF(AL(I,N) .GT. HIALFA .OR. AL(I,N) .LT. LOALFA)XMACHT=0.
      IF(N .LE. NSPAR) GO TO 27
```

```
      IF(SYM.NE.0.) ALTAB=AL(I,N)                                       GRP04380
      CALL BLIN4 (CLT,NB,5,15,100,CL(I,N),ALTAB,XMACHT,L1)              GRP04390
      CALL BLIN4 (CDT,NB,5,15,100,CD(I,N),ALTAB,XMACHT,L2)              GRP04400
      IF (L1 + L2 .EQ.2) GOTO 107                                       GRP04410
      IERR =  1                                                         GRP04420
  106 IF(IERR .EQ. 0) GOTO 8001                                         GRP04430
      WRITE(6,8821)                                                     GRP04440
      WRITE(6,8823) ALTAB,XMACHT,LL,N,XX(N),IPSI(I),L1,L2               GRP04450
      IF(IERR .EQ. 1) GOTO 5000                                         GRP04460
 8001 WRITE(6,8822)                                                     GRP04470
      WRITE(6,8823) ALTAB,XMACHT,LL,N,XX(N),IPSI(I),L1,L2               GRP04480
      IF (IERR .EQ. 0) GOTO 5000                                        GRP04490
  107 CD(I,N)=CD(I,N)  + DELD                                           GRP04500
      IF (N.EQ.1) CL(I,1)=0.0                                           GRP04510
      GOTO 172                                                          GRP04520
   27 IF (SYMSPR .NE. 0.) ALTAB=AL(I,N)                                 GRP04530
      CALL BLIN4 (BSCLT,1,1,5,71,CL(I,N),ALTAB,XMACHT,L1)               GRP04540
      CALL BLIN4 (BSCDT,1,1,5,71,CD(I,N),ALTAB,XMACHT,L2)               GRP04550
      IF (L1 + L2 .EQ. 2) GOTO 172                                      GRP04560
      IERR=0                                                            GRP04570
      GOTO 106                                                          GRP04580
  172 IF (N.EQ.NSEG) CL(I,N)=0.                                         GRP04590
      IF (ABS(SWPCOS(N)) .LT. .5) CL(I,N)=.5*CL(I,N)                    GRP04600
      IF (ABS(SWPCOS(N)) .LT. .3) CL(I,N)=0.0                           GRP04610
      IF(AL(I,N).GE.0..OR.SYM.NE.0.) GO TO 5                            GRP04620
      CL(I,N)=-CL(I,N)                                                  GRP04630
    5 UCD(N)=ABS(U(N))*CRDX(N)                                          GRP04640
      LOAD(I,N)=(CL(I,N)*(UTUR(N))+CD(I,N)*UP(N))*ABS(U(N))*XLFC(N)     GRP04650
      CU = CD(I,N)*UTUR(N)*UCD(N)                                       GRP04660
      H(1)=H(1)+CU                                                      GRP04670
      H(2)=H(2)+CU*X(N)                                                 GRP04680
      CU=CL(I,N)*UP(N)*UCD(N)                                           GRP04690
      H(3)=H(3)+CU                                                      GRP04700
      H(4)=H(4)+CU*X(N)                                                 GRP04710
      CU =  (CL(I,N)*UTUR(N)+CD(I,N)* UP(N))*UCD(N)                     GRP04720
      H(5)=H(5)+CU                                                      GRP04730
      H(6)=H(6)+CU*X(N)                                                 GRP04740
   28 AM=AM+CU*X(N)                                                     GRP04750
C***********************************************************************GRP04760
      AM=AM/SR                                                          GRP04770
C COMPUTE FORCE COEFFICIENTS AROUND AZIMUTH                             GRP04780
      CQL(I )=(ER*H(3)+H(4)*YCOS)/TWOPI                                 GRP04790
      CQD(I )=(ER*H(1)+H(2)*YCOS)/TWOPI                                 GRP04800
      CQ(I)=CQD(I)-CQL(I)                                               GRP04810
      CZ(I )=-H(5)*YCOS/TWOPI                                           GRP04820
      H13=H(1)-H(3)                                                     GRP04830
      CX(I )=(H(5)*YSIN*ZCOS-ZSIN     *H(1)+H(3)*ZSIN)/TWOPI            GRP04840
      CY(I )=(-H(5)*YSIN*ZSIN-ZCOS*H13)/TWOPI                           GRP04850
      HEYH=-H(5)*ER*YCOS-H(6)                                           GRP04860
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      H24=H(2)-H(4)
      CP(I )=(HEYH*ZCOS-YSIN*ZSIN*H24*(1.-INPL))/TWOPI
      XR(I )=(HEYH*ZSIN-YSIN*ZCOS*H24*(1.-INPL))/TWOPI
      MG = 2.* PHSO* ZCOS- 2.*THFO* ZSIN
      BPP(I) =(AM-CWM-(BP(I)*FDMP+(B (I)-PCR)*SFH/OM)/(SMOM*OM))+MG
      IF(SMOM.EQ.0.) BPP(I) = 0.0
      XMH2 = ( BPP(I)*YCOS-BP(I)**2*YSIN )
      HM(I) = FMEOR*XMH2*ZCOS+ER*CZ(I) *ZCOS-(SFH*(B(I)-PCR)*ZCOS) /
     1(RHO*PI*OMEGAR**2 *R**3)
      HL(I) = FMEOR*XMH2*ZSIN+ER*CZ(I) *ZSIN-(SFH*(B(I)-PCR)*ZSIN) /
     1(RHO*PI*OMEGAR**2 *R**3)
C     PRINT TRANSIENT AND/OR DEBUGGING IF DESIRED
      IF ((XMESS(2)+XMESS(1)).EQ.0.)  GO TO 30
      IF(LL.EQ.1.AND.I.EQ.2) WRITE (6,94) B(1),BP(1),BPP(1)
      NPSI=IPSI(I)
      IF (XMESS(1).EQ.0.)  GO TO 299
      IF (I.GT.2)  GO TO 298
      WRITE (6,58)
  298 WRITE(6,91) NPSI,LL,B(I),BP(I),BPP(I), (UP(N),UT(N),U(N),PHI(I,N),
     1AL(I,N),XMACH(I,N), CL(I,N),CD(I,N), LOAD(I,N),N=1,NSEG)
      GO TO 30
  299 WRITE (6,92) NPSI,LL,B(I),BP(I),EPP(I)
   30 CONTINUE
C*********************************************************************
C SAVE STARTING VALUES AT PSI = 0
      BO(LL)=B(1)
      BPO(LL)=BP(1)
      BPPO(LL)=BPP(1)
      IF (LL.LT.2) GO TO 113
C TEST FOR FLAPPING CONVERGENCE
      CONV=(ABS(B(KP1)-B(1)).LE.BTOL).AND.(ABS(EP(KP1)-EP(1)).LE.BPTOL)
      IF(CONV) GO TO 711
      IF(LL.LT.NTRL) GO TO 113
      IF(.NOT.(SHIN.AND.ITN.LT.ITLIM).AND.PRNT) WRITE (6,34)
C ********************************************************************
C
C     COMPUTE AND PRINT HARM. ANAL. OF BETA IN DEGREES
C
 711  BD(1)=B(1)*RC
      CALL HARM(K ,6,BD,0.0,A0,BUF1,BUF2,BUF3,BUF4,BUF5,I)
      IF (.NOT.A1B1) GO TO 164
C     COMPUTE DELTA A1S AND B1S
      DA1S = (BUF1(1)-RA1S)*IGC
      DB1S = (BUF2(1)-RB1S)*IGC
C INTEGRATE FORCE COEFFICIENTS AROUND AZIMUTH
  164 XCQL=CQL(2)
      XCQD=CQD(2)
      XCQ=CQ(2)
      XCZ=CZ(2)
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      XCX=CX(2)                                                         GRP05360
      XCY=CY(2)                                                         GRP05370
      XXR=XR(2)                                                         GRP05380
      XCP=CP(2)                                                         GRP05390
      XHM = HM(2)                                                       GRP05400
      XHL = HL(2)                                                       GRP05410
      DO 601 I=3,KP1                                                    GRP05420
      XCQL=XCQL+CQL(I)                                                  GRP05430
      XCQD=XCQD+CQD(I)                                                  GRP05440
      XCQ=XCQ+CQ(I)                                                     GRP05450
      XCZ=XCZ+CZ(I)                                                     GRP05460
      XCX=XCX+CX(I)                                                     GRP05470
      XCY=XCY+CY(I)                                                     GRP05480
      XXR=XXR+XR(I)                                                     GRP05490
      XHM = XHM+HM(I)                                                   GRP05500
      XHL = XHL+HL(I)                                                   GRP05510
  601 XCP=XCP+CP(I)                                                     GRP05520
C***  COMPUTE TOTAL FORCES****************************                  GRP05530
      XK=K                                                              GRP05540
 1750 F=XNB/XK*HK                                                       GRP05550
      FR=F*R                                                            GRP05560
      CMF=OM/550.                                                       GRP05570
      Q=XCQ*FR                                                          GRP05580
      HP=Q*OMF                                                          GRP05590
      PHP=XCQD*FR*OMF                                                   GRP05600
      ZF=XCZ*F                                                          GRP05610
      XF=XCX*F                                                          GRP05620
      YF=XCY*F                                                          GRP05630
      RM=XXR*FR                                                         GRP05640
      PM=XCP*FR                                                         GRP05650
      XLH = XHL*FR                                                      GRP05660
      XMH = XHM*FR                                                      GRP05670
      AX=ALLR                                                           GRP05680
      IF(.NOT.USVL.OR.UVL.LT.0.) AX=ATAN(LAMBDA/MU-(ZF/HK)/(2.*MU*SQRT(LGRP05690
     1AMBDA**2+MUSQ)))                                                  GRP05700
      ALS=AX*RC                                                         GRP05710
      ALC=ALS-B1S                                                       GRP05720
      AR=ATAN(RD/RL)                                                    GRP05730
      XRC=SQRT(ZF**2+XF**2)                                             GRP05740
      RR=SQRT(RL**2+RD**2)                                              GRP05750
      CA=COS(AX)                                                        GRP05760
      SA=SIN(AX)                                                        GRP05770
      XCL=-ZF*CA+XF*SA                                                  GRP05780
      XCD=-ZF*SA-XF*CA                                                  GRP05790
      AC=ATAN2(XCD,XCL)                                                 GRP05800
      VAC=MU*OMEGAR/CA/1.688                                            GRP05810
      IF (.NOT.ALFA) MU=VEL/VAC*MU                                      GRP05820
      MUSQ=MU**2                                                        GRP05830
      EQD=326.*HP/VAC+XCD                                               GRP05840
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      EQLD=XCL/EQD
      EQPA=EQD/RHO*.70116482/VAC**2
      ALR=ALC/RC
      W=ATAN2(SIN(A1R)/COS(A1R),CA)
      SW=SIN(W)
      CW=COS(W)
      TAU=ATAN(SIN(ALR)/COS(ALR)*CW)
      STAU=SIN(TAU)
      CTAU=COS(TAU)
      THR=XF*(SA*CW*CTAU-CA*STAU)-ZF*(CA*CTAU*CW+SA*STAU)+YF*SW*CTAU
      CT=THR/HK
      HF=-XF*(CA*CTAU+SA*STAU*CW)-ZF*(SA*CTAU-CA*STAU*CW)-YF*SW*STAU
      CH=HF/HK
      CLP=XCL/HK
      CDP=XCD/HK
      CTOS=CT/RS
      CHOS=CH/RS
      CLPOS=CLP/RS
      CDPOS=CDP/RS
      RES=SQRT(XF**2+YF**2+ZF**2)
      LRF=100./(XCL*R)
      LATD=RM*LRF
      LONGD=PM*LRF
      CQANS = Q/(HK*R)
      CQOS =  CQANS/RS
C*****************************************************************
C**** APPLY MAJOR ITERATION CONVERGENCE CRITERIA *********************
 1500 IF (XITLIM.EQ.0.) GO TO 116
      MCONV=ABS(RL-XCL).LE.XLTOL
      IF(.NOT.ALFA) MCONV=MCONV.AND.ABS(RD-XCD).LE.XDTOL
      IF(SHIN) MCONV=MCONV.AND.CONV
      IF(ABIT.NE.0.) MCONV=MCONV.AND.ABS(DA1S).LE.TOLAB.AND.ABS(DB1S).LE
     1.TOLAB
      IF (TRIM.NE.0.)MCONV=MCONV.AND.AES(RM).LE.100..AND.ABS(PM).LE.100.
C ****************************************************************
C IF MAJ. IT. CONVERGED GO TO FINAL PRINTOUT, IF NOT TEST FOT IT. LIMIT
C ****************************************************************
      IF (SKIP.GT.0..AND..NOT.MCONV)   GO TO  1699
116   WRITE (6,58)
      WRITE (6,142)  A1S,B1S,A2S,B2S,T75,LAMBDA,MU ,MUY
      WRITE (6,180) CT,CH,CLP,CDP,CTOS,CHOS,CLPOS,CDPOS,CQANS,CQOS
      WRITE (6,181) XCL,XF,RES,XCD,YF,RM
      WRITE (6,182)  HP,ZF,PM,EQD,EQLD,EQPA,ALS,THR,Q
      WRITE (6,183) ALC,HF,PHP,LATD,VAC,LONGD,      XMH,XLH,ITN
      IF (XITLIM.EQ.0.) GO TO 115
 1699 IF (MCONV) GO TO 115
C !!**************************************************************
C IF LIMIT NOT EXCEEDED ALTER PARAMETERS, OTHERWISE PRINT FAILURE MESSAG
C ****************************************************************
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```
      IF (ITN.LT.ITLIM) GO TO 51                                        GRP06340
 1700 CONTINUE                                                          GRP06350
      WRITE (6,48)                                                      GRP06360
      WRITE (6,56)                                                      GRP06370
      WRITE (6,48)                                                      GRP06380
      ITN=ITN+1                                                         GRP06390
      GO TO 115                                                         GRP06400
C**** ALTER PARAMETERS ACCORDING TO CPTIONS **************************** GRP06410
   51 RSF=RS*5.73                                                       GRP06420
      DATH=16.*MU/(6.-3.*MUSQ)+RSF/(12.*MUSQ)                           GRP06430
      DAL=4.*MU/(2.-MUSQ)+1./MU+RSF/(8.*MUSQ)                           GRP06440
      HR=HK*RS/2.                                                       GRP06450
      HJ=.47+.28*MUSQ                                                   GRP06460
      HR5=HR*5.73                                                       GRP06470
      DRTH=HR5*(.3+.48*MUSQ)                                            GRP06480
      DRL=HR5*HJ                                                        GRP06490
      ABF=0.                                                            GRP06500
      DAB=4.*MUSQ/(MUSQ-2.)-RSF/(8.*MU)-1.                              GRP06510
      DRB=-DRL*MU                                                       GRP06520
      IF (.NOT.A1B1) GO TO 52                                           GRP06530
      FEI = ATAN2( C75*R4/1760.,((3.- 8.*ER +6.*ER**2)/(ER*R *FMOM *    GRP06540
     1 (  1.0  ) +SFH/OMS)))                                            GRP06550
      A1S = A1S-(DA1S*COS(FEI) +DB1S* SIN(FEI))                         GRP06560
      ABF = DA1S*SIN(FEI)- DB1S*COS(FEI)                                GRP06570
      B1S=B1S+ABF                                                       GRP06580
      ABF=ABF/RC                                                        GRP06590
   52 DELR=RR-XRC-DRB*ABF                                               GRP06600
      DELA=AR-AC-DAB*ABF                                                GRP06610
      DRALTH=DRL*DATH-DRTH*DAL                                          GRP06620
      DTH=(RL-XCL-DRB*ABF)/DRTH*RC*IGC*(1.-TOP)                         GRP06630
      DLMDA=(RL-XCL-DRB*ABF)/DRL*IGC*TOP                                GRP06640
      IF (ALFA) GO TO 888                                               GRP06650
      DTH=(DRL*DELA-DAL*DELR)/DRALTH*RC*IGC                             GRP06660
      DLMDA=(DATH*DELR-DRTH*DELA)/DRALTH*IGC                            GRP06670
      IF (.NOT.USVL) GO TO 888                                          GRP06680
      DALFA=DLMDA/MU                                                    GRP06690
      ALLR=ALLR+DALFA                                                   GRP06700
  888 IF (ABS(DTH/10.).GT..5)  DTH = SIGN(.5*10.,DTH)                   GRP06710
      IF (ABS(DLMDA/0.0200).GT..4)   DLMDA = SIGN(.4*0.0200,DLMDA)      GRP06720
      T75=T75+DTH                                                       GRP06730
  311 LAMBDA=LAMBDA+DLMDA                                               GRP06740
      ITN=ITN+1                                                         GRP06750
C ***********************************************************************GRP06760
C**** TEST FOR LIFT CURVE SLOPE LESS THAN ACCEPTABLE MINIMUM *********  GRP06770
      IF (ITN.EQ.1) GO TO 952                                           GRP06780
      IF (.NOT.ALFA) GO TO 115                                          GRP06790
      TEMP=XCL-TEMP                                                     GRP06800
      A=TEMP/DTP*RC/DRTH*5.73                                           GRP06810
      IF (A.LT.ATEST) TEST=.FALSE.                                      GRP06820
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      IF (.NOT.TEST) WRITE (6,951) A,ATEST                              GRP06830
  952 TEMP=XCL-DRB*ABF                                                  GRP06840
      DTP=DTH                                                           GRP06850
C ***********************************************************************GRP06860
C     PRINT INITIAL BETA, *, AND **, AND SUMMARY OF FINAL REV.          GRP06870
  115 IF (XMESS(6).EQ.1..AND.MCONV)  GO TO 2501                         GRP06880
      GO TO 1501                                                        GRP06890
 2501 WRITE (6,58)                                                      GRP06900
      WRITE (6,134)                                                     GRP06910
      LL=LL-1                                                           GRP06920
      DO 132 I=1,LL                                                     GRP06930
  132 WRITE (6,133) I,BO(I ),BPO(I ),BPPO(I )                           GRP06940
      LL= LL + 1                                                        GRP06950
      WRITE (6,135) LL                                                  GRP06960
      MM=K/2+1                                                          GRP06970
      DO 136 I=1,MM                                                     GRP06980
      L=I+MM-1                                                          GRP06990
  136 WRITE (6,137) IPSI(I),B(I),BP(I),BPP(I),IPSI(L),B(L),BP(L),BPP(L) GRP07000
      WRITE (6,160)                                                     GRP07010
      WRITE (6,161) AO, (BUF1(I),I=1,6)                                 GRP07020
      WRITE (6,162) (BUF2(I),I=1,6)                                     GRP07030
C             ***************************************************       GRP07040
 1501 IF (XMESS(5).EQ.1..AND.MCONV)  GO TO 2502                         GRP07050
      GO TO 1502                                                        GRP07060
C**   COMPUTE AND PRINT AVERAGES**************************              GRP07070
 2502 WRITE(6,58)                                                       GRP07080
      WRITE (6,148)                                                     GRP07090
      DO 143 I=2,KP1                                                    GRP07100
  143 WRITE (6,144) IPSI(I),(FC(I,J),J=1,8)                             GRP07110
      DO 602 I=1,8                                                      GRP07120
  602 AV(I)=TF(I)/XK                                                    GRP07130
      WRITE (6,145) (AV(I),I=1,8)                                       GRP07140
      DO 603 I=1,8                                                      GRP07150
  603 AV(I)=XNB*AV(I)                                                   GRP07160
      WRITE (6,146) (AV(I),I=1,8)                                       GRP07170
      DO 604 I=1,8                                                      GRP07180
  604 AV(I)=AV(I)/RS                                                    GRP07190
      WRITE (6,147) (AV(I),I=1,8)                                       GRP07200
      MM=K/2 + 1                                                        GRP07210
      I=MM + 1                                                          GRP07220
      DO 151 J=I,KP1                                                    GRP07230
      IF(CQD(I) .LT. CQD(J)) GO TO 152                                  GRP07240
  151 CONTINUE                                                          GRP07250
      GO TO 154                                                         GRP07260
  152 I = J                                                             GRP07270
  154 BCQDOS=CQD(I)*XNB/RS                                              GRP07280
      WRITE (6,153) BCQDOS,IPSI(I)                                      GRP07290
C             ***************************************************       GRP07300
C     COMPUTE AND PRINT HARM. ANAL. OF CZ IF DESIRED                    GRP07310
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```
 1502 IF (XMESS(4).EQ.1..AND.MCONV)   GO TO 2503
      GO TO 1503
 2503 DO 902 I=1,K
  902 CZ(I)=CZ(I+1)
      WRITE (6,58)
      WRITE (6,901)
      CALL HARM (K,6,CZ,DPSI,A0,BUF1,BUF2,BUF3,BUF4,BUF5,L)
      A0=A0*HK
      DO 900 I=1,6
      BUF1(I)=-BUF1(I)*HK
  900 BUF2(I)=-BUF2(I)*HK
      WRITE (6,161) A0,(BUF1(I),I=1,6)
      WRITE (6,162) (BUF2(I),I=1,6)
C ****************************************************************************
C**** PRINT DATA SECTION AT SPECIFIED INTERVAL IF DESIRED *************
 1503 IF (XMESS(7).EQ.1..AND.MCONV)   GC TO 2505
      GO TO 523
 2505 WRITE (6,58)
      NP=ABS(PPSI)/DPSI+1.1
      NPL1=NP-1
      NPL12=NPL1*2
      KLN=KP1-NPL1
      DO 73 I=NP,KLN,NPL12
      J=I+NPL1
      PSIP=IPSI(I)
      WRITE (6,71) IPSI(I),IPSI(J)
   73 WRITE(6,72) (XX(N),AL(I,N),XMACH(I,N),CL(I,N), CD(I,N),PHI(I,N),
     1LOAD(I,N),SWEEP(I,N),AL(J,N),XMACH(J,N),CL(J,N),CD(J,N),PHI(J,N),
     2LOAD(J,N),SWEEP(J,N), N=1,NSEG)
C ****************************************************************************
C     COMPUTE AND PRINT HARMONICS OF AIR LOADS IF DESIRED
 523  IF (XMESS(3).EQ.1..AND.MCONV)   GO TO 2506
      GO TO 47
 2506 WRITE (6,519)
      DO 521 N=1,NSEG
      DO 520 I=1,K
  520 DUM(I)=LOAD(I+1,N)
      NH=MIN1(180./DPSI+.1,10.)
      CALL HARM (K,NH,DUM,DPSI,A0,BUF1,BUF2,BUF3,BUF4,BUF5,L)
      WRITE(6,522)N,A0,(BUF1(I),BUF2(I),BUF3(I),BUF4(I),BUF5(I),I=1,NH)
  521 CONTINUE
C ****************************************************************************
C     GO TO RESTART PROCEDURE IF INDICATED
C ****************************************************************************
   47 IF(XITLIM.NE.0..AND.ITN.LE.ITLIM.AND..NOT.MCONV.AND.TEST) GO TO
     1 1111
      GO TO 77
 1111 JEB = JEB + 1
      GO TO 6969
```

```
   77 JOY = 1
 6969 IF (JOY.GT.0) GO TO 5000
C***  MOMENT OPTION**********************************************
      IF (TRIM .EQ. 0.) GO TO 1710
      MOMITN=MOMITN + 1
      IF (MOMITN .GT. 1) GO TO 1701
      A1S1 = A1S
      B1S1 = B1S
      RM1 = RM
      PM1 = PM
      A1S = IGC * (A1S -.0006*RM)
      B1S = IGC * (B1S + .0007*PM)
      GO TO 1710
 1701 A1S2 = A1S
      RM2 = RM
      PM2 = PM
      B1S2  = B1S
      B1S = IGC * (B1S2*PM1-PM2*B1S1)/(PM1-PM2)
      A1S = IGC * (A1S2*RM1-RM2*A1S1)/(RM1-RM2)
      ABF=B1S/RC
 1710 CONTINUE
      IF (JEB.LE.15) GO TO 70
      WRITE (6,808)
C ******************************************************************
C     GO TO NEXT CASE IF LOC. 99 NOT EQ. ANY NEG NUMBER.
C ******************************************************************
 5000 JOY = 0
      JEB = 0
      IF (XEND.EQ.2.) GO TO 2000
      IF (XEND.GE.0.) GO TO 1000
      WRITE (6,5001)
 6666 STOP
   25 FORMAT(    66X,28HUSING SHORT ITERATION SCHEME)
   34 FORMAT(////1H 42(1H*),5X,25HFLAPPING DID NOT CONVERGE,5X,42(1H*))
   38 FORMAT(    /16H REQUIRED LIFT =F9.2, 8X15HREQUIRED DRAG =F8.2,10X23
     1HMAJOR ITERATION LIMIT =I3//16H LIFT TOLERANCE=F9.2, 8X15HDRAG TOL
     2ERANCE=F8.2)
   39 FORMAT(53H0ALPHA OPTION HAS BEEN REQUESTED - - - INPUT ALPHA = F8.
     14)
   48 FORMAT(1H0,119(1H*))
   56 FORMAT(1H0,39(1H*),5X,32HMAJOR ITERATION DID NOT CONVERGE,5X,38(1H
     1*))
   58 FORMAT  (1H1)
   69 FORMAT  (I2,10F7.0,/ (F9.0,9F7.0))
   71 FORMAT( //29X6HPSI = I4,9H  DEGREES44X6HPSI = I4,9H  DEGREES)
   72 FORMAT(132H0    X        ALPHA      MACH       CL        CD       PHI   L(LB/
     1IN)     SWEEP       ALPHA      MACH       CL        CD       PHI   L(LB/IN)
     2  SWEEP     //(F7.4,2X,6F8.3,F10.2,5X,6F8.3,F10.2))
  173 FORMAT(1H1,50X,'BLADE DATA',/)
```

```
74   FORMAT(1H1,50X,'SPAR DATA',/)                                          GRP08300
79   FORMAT(1X,I2,7X,10F10.3,/,(10X,10F10.3))                               GRP08310
80   FORMAT(1H1,2X,25HNAVAL AIR SYSTEMS COMMAND,4X,17HAIRFRAME DIVISIONGRP08320
    1,4X,19HAERO + HYDRO BRANCH, 4X,19HPERFORMANCE SECTION,4X,16HROTARYGRP08330
    5 WING UNIT/2X,'UNITED STATES NAVY    DEPARTMENT OF DEFENSE(?)'/53XGRPC8340
    3,16HINPUT QUANTITIES)                                                 GRP08350
 91 FORMAT(/7H0PSI = I3,9H  DEGREES,5H  REVI3,5X7HBETA = F11.8,5X8HBETGRPC8360
    1A* = F11.8,5X,9HBETA** = F11.8/                                       GRP08370
    2       120H0        UP          UT           U          PHI       ALGRP08380
    3PHA       MACH NO.        CL             CD       LOAD(LB/IN)/        GRPC8390
    4/ (9F12.7))                                                           GRP08400
 92 FORMAT (7H0PSI = I3,9H  DEGREES,5H  REVI3,5X7HBETA = F11.8,5X8HBETGRPC8410
    1A* = F11.8,5X,9HBETA** = F11.8)                                       GRP08420
 94 FORMAT(11H0BETA(0) = ,F11.8,5X,11HBETA*(0) = ,F11.8,5X,12HBETA**(0GRP08430
    1) = ,F11.8)                                                           GRPC8440
 95 FORMAT(17H0REQUESTED A1  = F10.4,6X16HREQUESTED B1  = F9.4,8X25HTOGRPC8450
    1LERANCE ON A1 AND B1 = F6.3)                                          GRP08460
133 FORMAT(1H029X,I2,3X,3F17.7)                                            GRP08470
134 FORMAT(    1H0,28X,3HREV,12X,7HBETA(0),10X,8HBETA*(0),8 X,9HBETA**GRPC8480
    1(0))                                                                  GRPC8490
135 FORMAT(29H0EQUILIBRIUM SOLUTION  REV = I2      /4H0PSI5X4HBETA8X5HGRP08500
    1BETA*6X6HBETA**        30X3HPSI5X4HBETA8X5HBETA*6X6HBETA**)          GRPC8510
137 FORMAT(I4,3F12.7,28XI3,3F12.7)                                         GRP08520
142  FORMAT(6H0  A1S,11X,3HB1S,11X, 3HA2S,11X,3HB2S,11X, 10HTHETA .75-,GRP08530
    111X,9HLAMBDA(S),11X,6HMU(X)S,11X,6HMU(Y)S/ 1X,F6.2,3F14.2,F18.2,     GRPC8540
    2F21.4,2F16.4)                                                         GRPC8550
144 FORMAT(I11,4X,8(1PE12.4))                                              GRP08560
145 FORMAT(15H0AVERAGE          ,8(1PE12.4))                               GRPC8570
146 FORMAT(15H (B) * AVE.       ,8(1PE12.4))                               GRPC8580
147 FORMAT(15H (B)*AV/SIG       ,8(1PE12.4))                               GRPC8590
148 FORMAT(//52X17HFORCE INTEGRATION//8X3HPSI10X2HCQ10X3HCQL9X3HCQD9X2GRP08600
    1HCZ,10X,2HCX,10X,2HCY,9X,4HCMHS,8X,4HCLHS,//)                         GRP08610
153 FORMAT(//  34X18HMAX B*CQD/SIGMA = F8.6,10H AT PSI = I3)               GRP08620
160 FORMAT(36X48HFOURIER COEFFICIENTS (WITH RESPECT TO THE SHAFT)//16XGRPC8630
    173HBETA  (DEG) = A0-A1*COS(PSI)-B1*SIN(PSI)-A2*COS(2*PSI)-B2*SIN(2*GRP08640
    2PSI)......)                                                           GRP08650
161 FORMAT(1H0  6X2HA012X2HA112X2HA212X2HA312X2HA412X2HA512X2HA6/7(1PEGRP08660
    114.4))                                                                GRPC8670
162 FORMAT(1H020X         2HB112X2HB212X2HB312X2HB412X2HB512X2HB6/14X6(GRP08680
    11PE14.4))                                                             GRP08690
169 FORMAT(F10.0)                                                          GRP08700
180 FORMAT(   //        10H0CT         =1PE14.6,7X9HCH         =1PE14.6,7X10HCGRP08710
    1L*        =1PE14.6,7X10HCD*        =1PE14.6/10H CT/SIGMA=1PE14.6,7X9HCGRP08720
    2H/SIGMA=1PE14.6,7X10HCL*/SIGMA=1PE14.6,7X10HCD*/SIGMA=1PE14.6/1X,9GRP08730
    3H CQ      =1PE14.6,7X,10HCQ*/SIGMA=1PE14.6)                           GRP08740
181 FORMAT(1H0/   8X,12HLIFT          =,F11.3,8H  POUNDS,8X,12HX FORCE    GRP08750
    1 =,F11.3,8H  POUNDS,8X,12HRESULTANT  =,F11.3,8H  POUNDS//8X,12HDRAGRPC8760
    2G       =,F11.3,8H  POUNDS,8X,12HY FORCE    =,F11.3,8H  POUNDS,8X,GRP08770
    312HROLL MOM    =,F11.3,11H  FT-POUNDS)                                GRP08780
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182 FORMAT(1H0,7X,12HHORSEPOWER =,F11.3,16X,12HZ FORCE     =,F11.3,8H  GRP08790
   1POUNDS,8X,12HPITCH MOM  =,F11.3,11H  FT-POUNDS//8X,12HEQUIV DRAG =GRP08800
   2,F11.3,8H  POUNDS,8X,12HEQUIV L/D  =,F11.3,16X,12HEQUIV P.A. =,F11GRP08810
   3.3,10H  SQ. FEET//8X,12HALPHA(S)   =,F11.3,9H  DEGREES,7X,12HTHRUSGRP08820
   4T      =,F11.3,8H  POUNDS,8X,12HTCRQUE      =,F11.3,11H  FT-POUNDS) GRP08830
183 FORMAT(1H0,7X,12HALPHA(C)   =,F11.3,9H  DEGREES,7X,12HH FORCE    =GRP08840
   1,F11.3,8H  POUNDS,8X,12HPROFILE HP =,F11.3,             //8X12HLAGRP08850
   2T. DIS.  =F11.3,9H  PERCENT7X12HV(ACTUAL)  =F11.3,7H  KNOTS9X12HLOGRP08860
   3NG. DIS. =F11.3,9H  PERCENT// 47X,                                 GRPC8870
   425HSHEARS HUB PITCH MOMENT =F10.2,4X 6HFT-LBS //47X               GRP08880
   525HSHEARS HUB ROLL MOMENT  =F10.2,4X 6HFT-LBS // ,47X,            GRP08890
   6 'MAJOR ITERATIONS USED =', I4,/119(1H*))                          GRPC8900
200 FORMAT(/ 5X7HSTATION15I7)                                           GRPC8910
201 FORMAT(14H0MASS SLUG/FT 15F7.4)                                     GRPC8920
202 FORMAT(8H0DELTA X6X15F7.4)                                          GRP08930
203 FORMAT(2H0X12X15F7.4)                                               GRP08940
204 FORMAT(11H0CHORD FEET3X15F7.4)                                      GRPC8950
205  FORMAT(11H0TWIST DEG.3X15F7.4)                                     GRPC8960
206  FORMAT(/,' BLADE DECK',1X,15F7.0)                                  GRPC8970
207 FORMAT(1H0,9X,18H  OMEGA-R          =F8.2,5X,30H   FT/SEC         GRPC8980
   1          , 15H  AG           =F8.2,5X,9H  DEGREES//10X,18H  RADIUSGRPC8990
   2         =F8.2,7X,27H FEET                         ,16H   BG       GRPC9000
   3    =F8.2,5X,9H  DEGREES//10X,18H  SPEED OF SOUND = F8.2,5X,30H   GRP09010
   4FEET/SEC                   , 15H  CG           =F8.2,5X,9H  DEGREESGRPC9020
   5//10X,18H  RHO             =F13.7, 30H   SLUGS/CUBIC FT.           GRP09030
   6 , 15H  TAN DELTA 3 =F8.2,5X,9H           )                         GRP09040
208 FORMAT(1H0,9X,18H  G                 = F8.2,5X,30H   FEET/SEC SQ.   GRP09050
   1          , 15H  E/R           = F10.4 // 10X,18H  NO. BLADES (B) =GRPC9060
   2 I5,   38X,15H  DELTA DRAG  = F10.4// 10X,18H  TIP MACH NO.   = F1GRP09070
   30.4,33X,15H  MOM-INERTIA = F13.7,15H  SLUG FEET SQ. // 10X,18H  SIGRP09080
   4GMA          =F10.4,33X,15H  SUM(DX)+E/R =F10.4//10X,18H  M(M)     GRP09090
   5       =F13.7,3X,9HSLUG FEET,18X,15H  VELOCITY     = F8.2,7X,5HKNOTGRP09100
   6S//12X16HTHRUST FACTOR  =F9.0,            34X15H  DELTA PSI   =I6GRP09110
   7, 9X7HDEGREES//12X16HFLAP DAMPER    =F9.0,7X19HFT. LB./RADIAN/SEC.GRP09120
   810X13HHINGE SPRING=F9.0,6X14HFT. LB./RADIAN/ 12X16HIT. GAIN CON.  GRP09130
   9=F8.2,37X13HPRE-CONING  =  F10.4,5X7HDEGREES/ 12X16HTAN D3 BAR     GRP09140
   * =F8.2,37X15HD3 BAR PHASE  =  F 8.4,5X7HDEGREES)                   GRPC9150
211 FORMAT(20H TOLERANCE ON BETA = F8.5,5X,20HTOLERANCE ON BETA* = F8.GRP09160
   15,5X,27HFLAPPING ITERATION LIMIT = I2)                             GRP09170
225 FORMAT( 12X16HFS(CG)             =F8.3,8X19HINCHES            10X    GRPC9180
   113HV(Y)S        =F9.3,6X 14HKNOTS          )                       GRP09190
226 FORMAT( 12X16HFS(MR)             =F8.3,8X19HINCHES            10X    GRP09200
   113HPSI *        =F9.3,6X 14HRADIANS/SEC    )                       GRPC9210
227 FORMAT( 12X16HWL(CG)             =F8.3,8X19HINCHES            10X    GRPC9220
   113HPHI *        =F9.3,6X 14HRADIANS/SEC    )                       GRPC9230
228 FORMAT( 12X16HWL(MR)             =F8.3,8X19HINCHES            10X    GRP09240
   113HTHETA(F) *  =F9.3,6X 14HRADIANS/SEC    )                       GRP09250
500 FORMAT(I3)                                                          GRPC9260
501 FORMAT(E15.6)                                                       GRP09270
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  502 FORMAT (5E14.6)                                                   GRP09280
  519 FORMAT(1H1////27X22HHARMONICS OF AIR LOADS)                       GRP09290
  522 FORMAT(// 8HOSTATIONI3,5X5HA0 = F11.7//10X,1HA,14X,1HB,14X,1HC,13XGRP09300
     1,3HPHI,11X,5HRATIO/ (5F15.7))                                     GRP09310
  585 FORMAT(1H )                                                       GRP09320
  808 FORMAT (1H019X44HSUBROUTINE PTONE CALLED MORE THAN  15  TIMES)    GRP09330
  901 FORMAT(42X35HHARMONIC ANALYSIS OF DIMENSIONAL CZ//27X66HCZ = A0+A1GRP09340
     1*COS(PSI)+B1*SIN(PSI)+A2*COS(2*PSI)+B2*SIN(2*PSI)+......//)       GRP09350
  951 FORMAT(19HOLIFT CURVE SLOPE (F6.2,38H) LESS THAN MINIMUM ACCEPTABLGRP09360
     1E VALUE (F4.2,1H)//67H STALL CRITERION HAS BEEN VIOLATED -- WILL GGRP09370
     2O TO NEXT CASE (IF ANY))                                          GRP09380
 1010 FORMAT (9H OCASE NO.I3)                                           GRP09390
 1604 FORMAT(40HOTROUBLE WITH LAMBDA CCNV. STATEMENT 225  2F10.6)       GRP09400
 5001 FORMAT(47H1END GENERALIZED ROTOR PERFORMANCE CALCULATIONS)        GRP09410
 8821 FORMAT(//,1X,'CL AND / OR CD LOOKUP PROBLEM WITH BLADE DATA')     GRP09420
 8822 FORMAT(//,1X,'CL AND / OR CD LOOKUP PROBLEM WITH SPAR DATA')      GRP09430
 8823 FORMAT(82X, 17HNATURE OF PROBLEM /8X,4HALFA ,7X,8HMACH NO. ,8X,4HRGRP09440
     1EV. , 6X,7HSEGMENT ,12H  BLADE STA. ,6X,3HPSI ,10X,2HCL ,10X,2HCD GRP09450
     2/,1X,2F12.3,2I12,F12.4,I12,5X,I7,5X,I7,                           GRP09460
     3 //,' 1=NO PROBLEM, 2=LO MACH, 3=HI MACH, 4=LO ALPHA, 5=HI ALPHA')GRP09470
      END                                                               GRP09480
      SUBROUTINE LOADED (UNPUT)                                         GRP09490
      DIMENSION UNPUT(5),C(5)                                           GRP09500
      WRITE (6,2)                                                       GRP09510
2     FORMAT (1H1,18HINPUT CARD LISTING  //)                            GRP09520
    6 READ(5,1) NNUM,NLOC, (C(I),I=1,5)                                 GRP09530
    1 FORMAT(I2,I4,5F12.0,I6)                                           GRP09540
      IF(NNUM.GT.5) NNUM=NNUM/10                                        GRP09550
      J=IABS(NNUM)                                                      GRP09560
      WRITE (6,3) NNUM,NLOC, (C(I),I=1,J)                               GRP09570
3     FORMAT (1X,I2,I4,5F20.10)                                         GRP09580
      IF(NLOC.NE.0) LOC=NLOC                                            GRP09590
      DO 4 I=1,J                                                        GRP09600
      UNPUT(LOC)=C(I)                                                   GRP09610
    4 LOC=LOC+1                                                         GRP09620
      IF(NNUM) 5,7,6                                                    GRP09630
    7 WRITE (6,8)                                                       GRP09640
  8   FORMAT(1H0, 52X,21HWORD COUNT IS MISSING)                         GRP09650
    5 RETURN                                                            GRP09660
      END                                                               GRP09670
C *******************************************************************GRP09680
      SUBROUTINE BLIN4 (T,NB,NBD,M,K,Y,X,Z,L)                           GRP09690
      DIMENSION T(NBD,M,K)                                              GRP09700
      IF (Z-T(NB,1,2)) 10,5,5                                           GRP09710
    5 DO 1 J = 2,20                                                     GRP09720
      IF (T(NB,J,2)-Z) 1,2,2                                            GRP09730
    1 CONTINUE                                                          GRP09740
      GO TO 11                                                          GRP09750
  2   UZ=T(NB,J,2)                                                      GRP09760
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      EZ=T(NB,J-1,2)                                                    GRPC9770
      N=T(NB,J,1)*2. +1.                                                GRP09780
      IF (X-T(NB,J,3)) 12,7,7                                           GRP09790
    7 DO 3 I = 5,N,2                                                    GRP09800
      IF (T(NB,J,I)-X) 3,4,4                                            GRP09810
    3 CONTINUE                                                          GRPC9820
      GO TO 13                                                          GRPC9830
    4 UZUX=T(NB,J,I)                                                    GRP09840
      UZUY=T(NB,J,I+1)                                                  GRP09850
      UZLX=T(NB,J,I-2)                                                  GRP09860
      UZLY=T(NB,J,I-1)                                                  GRP09870
      N=T(NB,J-1,1)*2. +1.                                              GRP09880
      IF (X-T(NB,J-1,3)) 12,9,9                                         GRPC9890
    9 DO 6 I = 5,N,2                                                    GRPC9900
      IF (T(NB,J-1,I)-X) 6,8,8                                          GRPC9910
    6 CONTINUE                                                          GRP09920
      GO TO 13                                                          GRPC9930
    8 EZUX=T(NB,J-1,I)                                                  GRPC9940
      EZUY=T(NB,J-1,I+1)                                                GRP09950
      EZLX=T(NB,J-1,I-2)                                                GRPC9960
      EZLY=T(NB,J-1,I-1)                                                GRP09970
      UY = (UZLY - UZUY) / (UZUX - UZLX) * (UZUX - X) + UZUY            GRPC9980
      EY = (EZLY - EZUY) / (EZUX - EZLX) * (EZUX - X) + EZUY            GRPC9990
      Y = (UY - EY) / (UZ - EZ) * (Z - EZ) + EY                         GRP10000
      L = 1                                                             GRP10010
      RETURN                                                            GRP10020
   10 L = 2                                                             GRP10030
      RETURN                                                            GRP10040
   11 L = 3                                                             GRP10050
      RETURN                                                            GRP10060
   12 L = 4                                                             GRP10070
      RETURN                                                            GRP10080
   13 L = 5                                                             GRP10090
      RETURN                                                            GRP10100
      END                                                               GRP10110
C ***********************************************************************GRP10120
      SUBROUTINE HARM(K,NH,Y,ALPHA,AO,A,B,C,PHI,RATIO,LL)               GRP10130
      DIMENSION A(1),B(1),C(1),PHI(1),RATIO(1),Y(1)                     GRP10140
      PI = 3.14159                                                      GRP10150
      NK = NH                                                           GRP10160
      IF (NH) 15,15,18                                                  GRP10170
   15 NH = K / 2                                                        GRP10180
   18 IF (NH - K / 2) 10,10,210                                         GRP10190
   10 LK = K / 2                                                        GRP10200
      M = LK * 2                                                        GRP10210
      IF (K - M) 60,30,60                                               GRP10220
   30 HAN = NH                                                          GRP10230
      CAP = K / 2                                                       GRP10240
      IF (HAN - CAP) 40,35,40                                           GRP10250
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   35 NK = NH - 1                                        GRP10260
40    K1 = K / 2                                         GRP10270
      IF(NH.LT.K1) GO TO 60                              GRP10280
      A(K1) = 0.0                                        GRP10290
      B(K1) = 0.0                                        GRP10300
      DO 50 I = 1,K                                      GRP10310
50    A(K1) = A(K1) + ( - 1.0) ** (I - 1) * Y(I)         GRP10320
      A(K1) = A(K1) / FLOAT(K)                           GRP10330
60    A0 = 0.0                                           GRP10340
      DO 70 N = 1,K                                      GRP10350
70    A0 = A0 + Y(N)                                     GRP10360
      A0 = A0 / FLOAT(K)                                 GRP10370
      DO 90 J = 1,NK                                     GRP10380
      A(J) = 0.0                                         GRP10390
      B(J) = 0.0                                         GRP10400
      DO 90 I = 1,K                                      GRP10410
      PSI = 6.2831853 / FLOAT(K)                         GRP10420
      T = FLOAT(J) * FLOAT(I - 1)                        GRP10430
      A(J) = A(J) + Y(I) * COS(T * PSI)                  GRP10440
90    B(J) = B(J) + Y(I) * SIN(T * PSI)                  GRP10450
      DO 100 J = 1,NK                                    GRP10460
      A(J) = A(J) * 2.0/ FLOAT(K)                        GRP10470
100   B(J) = B(J) * 2.0/ FLOAT(K)                        GRP10480
      DO 195 J = 1,NH                                    GRP10490
      TT = FLOAT(J) * ALPHA / 57.295779                  GRP10500
      APR    = A(J) * COS(TT) - B(J) * SIN(TT)           GRP10510
      BPR    = A(J) * SIN(TT) + B(J) * COS(TT)           GRP10520
      A(J) =-APR                                         GRP10530
195   B(J) =-BPR                                         GRP10540
      DO 110 J = 1,NH                                    GRP10550
110   C(J) = SQRT(A(J) ** 2 + B(J) ** 2)                 GRP10560
      G = C(1)                                           GRP10570
      DO 140 J = 2,NH                                    GRP10580
      IF (G - C(J)) 130,130,140                          GRP10590
130   G = C(J)                                           GRP10600
140   CONTINUE                                           GRP10610
      DO 150 J = 1,NH                                    GRP10620
      IF (G)  152,151,152                                GRP10630
  151 RATIO(J) = 9999999.9999999                         GRP10640
      IF(C(J).EQ.0.)  RATIO(J) = 1.0                     GRP10650
      GO TO 150                                          GRP10660
152   RATIO(J) = C(J) / G                                GRP10670
  150 CONTINUE                                           GRP10680
      DO 180 J = 1,NH                                    GRP10690
      IF (B(J).EQ.0.)  GO TO 190                         GRP10700
      PN = A(J) / B(J)                                   GRP10710
      PHI(J) = ATAN(PN)                                  GRP10720
      IF (B(J)) 170,190,180                              GRP10730
170   PHI(J) = PHI(J) + 3.14159265                       GRP10740
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      GO TO 180                                         GRP10750
  190 PHI(J) = SIGN(PI/2. , A(J))                       GRP10760
  180 PHI(J) = PHI(J) * 57.295779                       GRP10770
  200 LL = 1                                            GRP10780
      RETURN                                            GRP10790
  210 LL = 2                                            GRP10800
      RETURN                                            GRP10810
      END                                               GRP10820
```

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